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THE CRYSTAL STRUCTURE OF AN IRON PHOSPHIDE

BY JAMES B. FRIAUF

Abstract

Crystals of the iron phosphide, Fe_2P , were prepared by adding electrolytic iron to a molten alloy of copper and phosphorus. Chemical analyses for iron and phosphorus showed that the crystals had the composition corresponding to the formula, Fe_2P . The density of the crystals was found to be 6.89.

The structure of these crystals was studied by X-ray methods, using the data from Laue and rotation photographs. The crystals were found to be hexagonal with $a = 5.87 \text{ \AA}$ and $c = 3.45 \text{ \AA}$. The unit cell contains three molecules of Fe_2P . The atomic arrangement was not determined in detail but it was shown that the atomic arrangement must be given by one of the space groups D_{3h}^1 or D_{3h}^3 .

INTRODUCTION

THE elementary constituents of alloys can be divided into three general classes: pure metals and metalloids, solid solutions, and intermetallic compounds.¹ The application of X-ray methods to the study of these constituents has led to the determination of the crystal structures of the metals commonly used in alloys and has thrown considerable light on the nature and structure of solid solutions. A knowledge of the crystal structure of the intermetallic compounds is

¹Jeffries and Archer, "The Science of Metals," McGraw-Hill Book Co., Inc., New York, 1924, p. 219.

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equally desirable in order that they may be readily identified by X-ray methods, but although some of these have been studied our knowledge of the structure of these compounds is less complete than it is for the other two types of constituents which occur in alloys. For this reason the crystal structure of Fe_2P , one of the compounds indicated by the equilibrium diagram for the iron-phosphorus system,² has been studied by X-ray methods. The size and shape of the unit cell for crystals of this compound have been determined, and a value for the density has been found which is appreciably greater than the values reported by previous investigators. The atomic arrangement has not been determined in detail but has been restricted to those arrangements which arise from two space groups.

PREPARATION AND CHEMICAL ANALYSIS OF THE CRYSTALS

The crystals used in this investigation were prepared by the addition of electrolytic iron to a molten alloy of copper and phosphorus containing about fifteen per cent phosphorus.^{3,4} The melt was allowed to cool slowly and the resulting ingot was treated with hot concentrated nitric acid. This treatment left a residue of needle-shaped crystals of hexagonal cross section and a silvery gray luster which are insoluble in hot concentrated nitric acid. The appearance of these crystals corresponds with the description which has been given by previous investigators.^{3,4}

The density of the crystals was determined by weighing in a specific gravity bottle. The mean of a number of determinations gave 6.89 for the density. This figure is so much greater than the values found in the literature, 6.57,³ 6.56,⁴ and 5.7⁵ that it seemed desirable to analyze the crystals in order to be sure that their composition corresponded to the formula, Fe_2P , and that they contained no appreciable amount of copper trapped within the crystals or occluded on their surface. The result of the chemical analysis gave 21.72 per cent phosphorus and 77.9 per cent iron which is in satisfactory agreement with the theoretical composition, 21.74 per cent phosphorus and 78.26 per cent iron. Furthermore, the density determined

²Haughton, *Journal, Iron and Steel Institute*, Vol. 115, 1927, p. 417.

³Maronneau, *Comptes Rendus*, Vol. 130, 1900, p. 656.

⁴Le Chatelier and Wologdine, *Comptes Rendus*, Vol. 149, 1909, p. 709.

⁵International Critical Tables, New York, 1926, Vol. 1, p. 129.

in this investigation is in entire agreement with the X-ray data while the other values are not; consequently it would seem that the previously reported values for the density of this compound are too low.

THE SIZE AND SHAPE OF THE UNIT CELL

The size and shape of the unit cell can be determined from data furnished by (1) powder photographs, or (2) rotation photographs. The powder method is the only one which can be used when the material to be studied consists of a finely divided powder; if, however, the material contains crystals a few millimeters long by a few tenths of a millimeter in cross section, the rotation method can be used and is to be preferred to the powder method because of the additional information which it supplies. The Laue method for the study of crystal structure is not well adapted to the precise determination of the dimensions of the unit cell, but if Laue photographs can be obtained they are highly useful for determining the symmetry of the crystal and for checking the correctness of the unit cell found by either of the other two methods. Since the crystals used in this investigation were large enough to give good Laue and rotation photographs, the rotation method was used to determine the size of the unit cell and the Laue photographs were employed to confirm the result obtained in this way.

In rotation or oscillation photographs, a single crystal is rotated through a complete revolution or is oscillated back and forth through an angle less than 360 degrees about an axis which is perpendicular to the incident beam of X-rays. It is usually desirable to mount the crystal in such a way that some important crystallographic direction coincides with the axis of rotation. The Laue photographs of Fe_2P show that the crystals are hexagonal⁶ and make it possible to determine the direction of the principal or hexagonal axis. Fig. 1 is a sketch of an oscillation photograph of Fe_2P taken with the crystal mounted in such a way that the hexagonal or c-axis of the crystal coincided with the vertical axis of rotation. The photograph was taken on a flat photographic plate placed perpendicular to the incident beam of X-rays and 10 centimeters distant from the crystal. The spots on the plate, due to the reflection by the atomic planes in the

⁶Hexagonal crystals have two axes, known as the a-axes, which are of equal length and which make an angle of 120 degrees with each other. The c-axis or principal axis is perpendicular to the plane of the a-axes and has a different length.

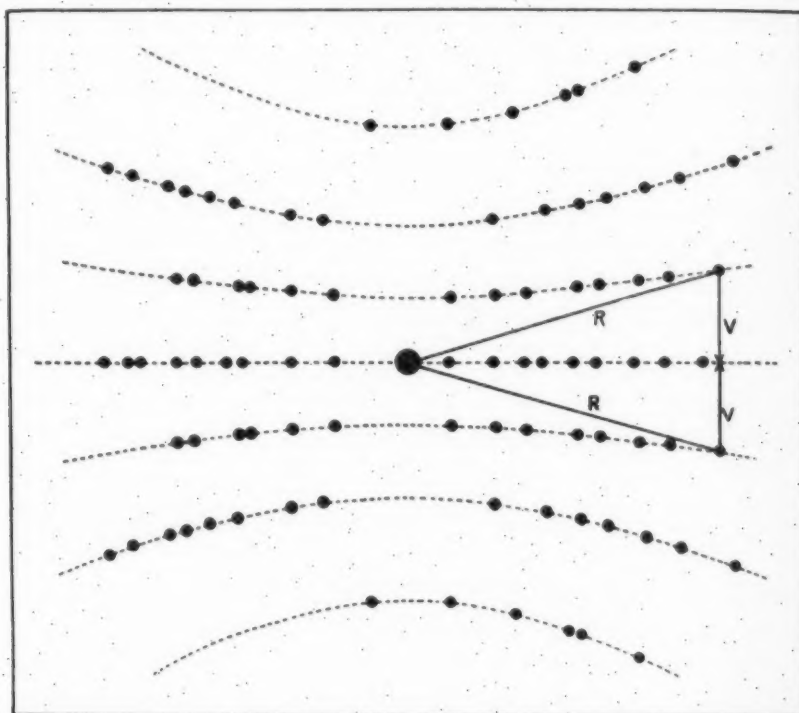


Fig. 1—Sketch of an Oscillation Photograph of a Crystal of Fe_2P .

crystal of the K radiation from molybdenum, lie on a horizontal straight line through the place where the undeviated beam of X-rays strikes the plate, and on a series of hyperbolas which are symmetrically placed above and below this line. The spots on the straight line constitute the principal spectrum, the other spots, the side spectra. Let R be the distance from a spot to the place where the undeviated beam of X-rays strikes the plate, and V the perpendicular distance from the spot to the principal spectrum. Since the photograph is symmetrical with respect to the principal spectrum it is advisable to measure the distance, $2V$, between two symmetrically placed spots and divide by two in order to obtain V . It can then be shown that⁷

$$\frac{V}{\sqrt{(R^2 + D^2)}} = \frac{l \lambda}{c} \quad (1)$$

where l is the third Miller index of the reflecting plane, λ is the wavelength of the X-rays used, and c is the height of the unit cell. V and

⁷Sommerfeld, "Atomic Structure and Spectral Lines," translation from the third German edition by H. L. Brose, p. 112.

Ewald, "Kristalle und Röntgenstrahlen," Berlin, 1923, p. 42.

Glocker, "Materialprüfung mit Röntgenstrahlen," Berlin, 1927, p. 230.

Table I
Data from an Oscillation Photograph

V		V	$\sin^2 \theta$	$\lambda^2 l^2$		λ^2	
$(R^2 + D^2)^{\frac{1}{2}}$	1	$1(R^2 + D^2)^{\frac{1}{2}}$	$\sin^2 \theta$	$4c^2$	$(h^2 + hk + k^2)$	$3a^2$	hkl
0	0	.....	0.01470	0.01470	3	0.00490	110
0.2063	1	0.2063	0.01539	0.00476	1	0.00476	101
0.2060	1	0.2060	0.02542	0.01479	3	0.00493	111
0.2063	1	0.2063	0.03025	0.01962	4	0.00490	201
0	0	.....	0.03442	0.03442	7	0.00492	210
0	0	.....	0.04401	0.04401	9	0.00489	300
0.2062	1	0.2062	0.04504	0.03441	7	0.00492	121
0	0	.....	0.06371	0.06371	13	0.00490	130
0.2052	1	0.2052	0.06963	0.05900	12	0.00492	221
0.2066	1	0.2066	0.07448	0.06385	13	0.00491	131
0.4135	2	0.2067	0.07684	0.03432	7	0.00490	122
0	0	.....	0.07809	0.07809	16	0.00488	400
0.4135	2	0.2067	0.08659	0.04407	9	0.00490	302
0.2059	1	0.2059	0.08896	0.07833	16	0.00490	401
0	0	.....	0.09312	0.09312	19	0.00490	230
0	0	.....	0.10276	0.10276	21	0.00489	410
0.2059	1	0.2059	0.10376	0.09313	19	0.00490	231
0.4117	2	0.2058	0.10643	0.06391	13	0.00492	132
0.2066	1	0.2066	0.11327	0.10264	21	0.00489	411
0.4111	2	0.2055	0.12088	0.07836	16	0.00490	402
0	0	.....	0.12229	0.12229	25	0.00489	500
0	0	.....	0.13221	0.13221	27	0.00490	330
0.2072	1	0.2072	0.13300	0.12237	25	0.00489	501
	Mean	0.2062			Mean	0.004896	

Hexagonal axes, $a = 5.876 \text{ \AA}$ and $c = 3.453 \text{ \AA}$.

R have already been defined and are shown in Fig. 1; D is the distance from the crystal to the plate.

Table I contains the data from an oscillation photograph of Fe_2P taken with the crystal oriented in such a way that the c-axis coincided with the axis of rotation. The first column contains $V(R^2 + D^2)^{-\frac{1}{2}}$ the second column, 1; and the third column $V(R^2 + D^2)^{-\frac{1}{2}}$ divided by 1. According to equation (1), the values in the third column should be equal to a constant, λ/c , and reference to the table shows that this condition is satisfied within the limits of experimental error. The mean value⁸ for the third column gives $\lambda/c = 0.2062$ and since $\lambda = 0.71208 \text{ Angstrom Unit (\AA)}$, $c = 3.453 \text{ \AA}$.

The fourth column of the table contains the values of $\sin^2 \theta$ for the different reflections where θ is the angle which occurs in the Bragg law of X-ray reflection. For hexagonal crystals $\sin^2 \theta$ is related to the dimensions of the unit cell by the equation⁹

$$\sin^2 \theta = \frac{\lambda^2}{3a^2} (h^2 + hk + k^2) + \frac{\lambda^2 l^2}{4c^2} \quad (2)$$

⁸ \AA (Angstrom unit) = 10^{-8} centimeters.

⁹Wyckoff, "The Structure of Crystals," New York, 1924, p. 98.

where a is the side of the base of the unit cell and c its height; h , k , and l are the Miller indices of the reflecting plane. The value of $\sin^2\theta$ for any reflection can be computed from R and D by means of the equation $R = D \tan 2\theta$; or a very considerable saving of time can be effected by the use of two nomograms¹⁰ which have been designed for the rapid computation of $\sin^2\theta$ and $V (R^2 + D^2)^{-1/2}$ from the measured values of R , V , and D . $\sin^2\theta$, λ , c , and l are now known, and equation (2) can be rewritten in the form

$$\sin^2 \theta - \frac{\lambda^2 l^2}{4c^2} = \frac{\lambda^2}{3a^2} (h^2 + hk + k^2) \quad (3)$$

where all the terms on the left hand side of the equation have known values. The fifth column of the table contains $\sin^2\theta - l^2 \lambda^2/4c^2$. According to equation (3), if each value in the fifth column of the table is divided by $(h^2 + hk + k^2)$, where h and k and the first two Miller indices of the reflecting plane which produces the spot, the quotient should be equal to the constant, $\lambda^2/3a^2$. The sixth column contains $(h^2 + hk + k^2)$ for the different reflecting planes, and the seventh column contains the quotient, $\lambda^2/3a^2$. The values in the seventh column are constant within the limits of experimental error and have an average equal to 0.004896. Hence $a = 5.876 \text{ \AA}$. The average of these figures for a and c with those obtained from other oscillation photographs gives $a = 5.87 \text{ \AA}$ and $c = 3.45 \text{ \AA}$ for the dimensions of the unit cell.

The correctness of this unit cell was checked by two other oscillation photographs taken with the crystal rotating about the $[1\ 0\ 0]$ and the $[1\ 2\ 0]$ directions.¹¹ In the analysis of these two photographs the graphical construction which has been described by Bernal¹² was used to determine which of the crystal planes would reach a position to reflect X-rays of the wave length used. No reflections were found on these photographs except such as were to be expected from a unit cell of the size chosen.

This unit cell is also in agreement with the data from Laue photographs in which the incident beam of X-rays made small angles with the $[0\ 0\ 1]$, $[1\ 0\ 0]$, and $[1\ 2\ 0]$ directions.¹¹ The computed

¹⁰Friauf, J. O. S. A. and R. S. I., 18, 479-487, 1929.

¹¹The $[0\ 0\ 1]$ direction is parallel to the c axis of the crystal. The $[1\ 0\ 0]$ direction is parallel to one of the a axes. The $[1\ 2\ 0]$ direction is perpendicular to the c -axis and to one of the a axes, and makes an angle of 30 degrees with the other a axis.

¹²Bernal, *Proceedings, Royal Society*, Vol. 113A, 1926, p. 117.

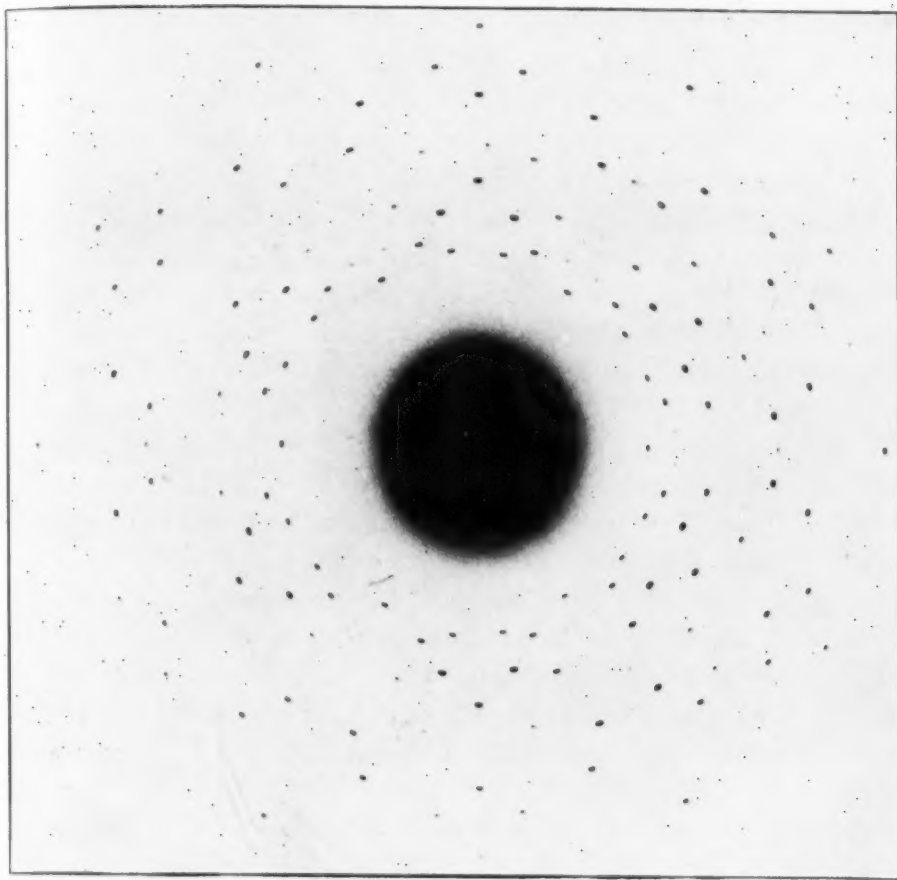


Fig. 2—Laue Photograph of a Crystal of Fe_2P .

wave lengths for the Laue spots on these photographs run down to but not below the short wave length limit of the X-rays used, and spots corresponding to reflections from planes of the same form for computed wave lengths slightly above and below the wave length of the silver absorption edge, show the characteristic differences in intensity to be expected due to the selective absorption of X-rays in the photographic plate.

The computed number of molecules of Fe_2P in the unit cell for a density of 6.89 is 3.01, or three within the limits of experimental error. The computed number of molecules in the unit cell must not differ from an integer by an amount greater than the experimental error. This condition is not satisfied if the previously reported values for the density of Fe_2P are used, and it would therefore seem that these values are too low.

THE LIMITATION OF THE POSSIBLE SPACE GROUPS

Fig. 2 is a reproduction of a Laue photograph of Fe_2P taken with the incident beam of X-rays parallel to the hexagonal axis of the crystal. The photograph shows a six-fold symmetry axis intersected by six planes of symmetry; hence the space group which gives the atomic arrangement in crystals of Fe_2P must be isomorphous with one of the point groups,¹³ D_{3h} , D_6 , C_{6v} , or D_{6h} . Comparison of the reflections found on the oscillation and Laue photographs with the space group criteria for hexagonal crystals¹⁴ shows that the only space groups which are not excluded by the observed reflections are D_{3h}^1 , D_{3h}^3 , C_{6v}^1 , D_6^1 , D_6^6 , and D_{6h}^1 . D_6^6 is unsuitable since it contains an even number of atoms in each group of equivalent positions, while there are three phosphorus atoms to be placed in the unit cell of Fe_2P . Two of the oscillation photographs show that the first order reflection from the (0 0 1) plane is much weaker than the second order; this observation eliminates all the arrangements which place the six iron atoms in the same plane parallel to the base of the unit cell. All the other arrangements which can be derived from D_6^1 , D_{6h}^1 , and C_{6v}^1 give the same structure factors for planes that are observed to reflect with decidedly different intensities. These space groups must consequently be excluded. This leaves the two space groups D_{3h}^1 and D_{3h}^3 as the only ones which can give the atomic arrangement in crystals of Fe_2P . The possible arrangements from either of these space groups contain several variable parameters. This makes the exact determination of the atomic positions a rather lengthy process and for this reason no attempt has been made to differentiate between the two possible space groups and to find the atomic arrangement.

COMPARISON WITH OTHER RESULTS

A recent paper in the *Zeitschrift für Physik*¹⁵ contains an account of an X-ray examination of the iron-phosphorus system. Powder photographs of alloys containing up to 27 per cent phosphorus

¹³Definitions of the point groups and space groups can be found in Wyckoff, "The Structure of Crystals," New York, 1924.

¹⁴Wyckoff, *Zeitschrift für Kristallographie*, Vol. 63, p. 507-537.
Astbury and Yardley, *Philosophical Transactions*, Royal Society of London, Vol. 224A, 1924, p. 221-257.

¹⁵Kreutzer, *Zeitschrift für Physik*, Vol. 48, 1928, p. 556.

were taken and were found to be in agreement with the equilibrium diagram obtained by the method of thermal analysis. The two compounds, Fe_3P and Fe_2P were found to give powder photographs very similar in appearance and it was therefore concluded that these two compounds crystallize in the same crystal system. Apparently the powder photographs obtained were not analyzed, but goniometer measurements were made on crystals of Fe_3P which show that this compound crystallizes in the tetragonal system with an axial ratio given by $a:c = 1:0.3482$. This conclusion is an agreement with previous measurements which also place Fe_3P in the tetragonal system with an axial ratio of $a:c = 1:0.3469$.¹⁶ If then, Fe_2P and Fe_3P both crystallize in the same crystal system, Fe_2P must also be tetragonal. However, the results of the X-ray examination of crystals of Fe_2P which are reported above leave no room for doubt that the crystals used in this investigation are hexagonal. The presence of a six-fold symmetry axis intersected by six planes of symmetry on the Laue photograph shown in Fig. 2 is in itself sufficient to establish that the crystal used is hexagonal since only hexagonal crystals are capable of giving a Laue photograph of this type. This discrepancy may be due to one of two causes. The crystals used in this investigation were formed from a melt which contained copper, iron, and phosphorus whereas the crystals used by Kreutzer were formed from a melt which contained only iron and phosphorus. It is perhaps possible that different allotropic modifications may be formed when Fe_2P crystallizes under different conditions. It seems more probable, however, that no real discrepancy is involved. Mere similarity in the appearance of powder photographs from different substances is not in itself a substantial foundation for the conclusion that the substances crystallize in the same crystal system, and a more detailed examination would be required to establish that this is the case. Unfortunately the paper by Kreutzer contains no data on the $\sin^2\theta$ values which were found on his powder photographs of Fe_2P and it is therefore impossible to compare these with the $\sin^2\theta$ values which would be given by a hexagonal unit cell of the dimensions found above.

It will be noticed that Fe_3P is tetragonal and Fe_2P is hexagonal although iron, which is the major constituent of both these compounds, is cubic. This is in agreement with the observation that there

¹⁶Spencer, *Journal, Iron and Steel Inst.*, Vol. 97, 1918, p. 190.

is no obvious relation between the symmetry of a compound and the symmetry of its elementary constituents.

AUTHOR'S ADDITION

When this paper was prepared the only previous X-ray study of the crystal structure of Fe_2P with which the author was acquainted was that contained in Kreutzer's paper.¹⁶ Since then his attention has been called to two papers by Hagg.¹⁷ He found that Fe_2P is hexagonal with $a = 5.852 \text{ \AA}$ and $c = 3.453 \text{ \AA}$. There are three molecules in the unit cell and the atomic arrangement is given by the space group D_{3h}^{3h} . The difference between the dimensions of the unit cell found by Hagg and the values found in this investigation are within the limits of experimental error; hence the two investigations can be said to be in agreement. The agreement of the results obtained in these two entirely independent studies strongly supports the conclusion that the structure deduced for crystals of Fe_2P is correct.

¹⁶Hagg, *Zeitschrift für Kristallographie*, Vol. 68, 1928, p. 470.

Hagg, *Nova Acta Reg. Soc. Scient. Upsala*, Vol. 7, 1929, p. 1.

ON THE DISTRIBUTION OF HARDNESS PRODUCED BY COLD WORKING

BY W. P. SYKES AND A. C. ELLSWORTH

Abstract

This paper presents a preliminary study of the progress of hardening throughout the section produced by cold working. Three materials, differing considerably in hardness, are reduced by cold swaging. Hardness measurements are taken at various depths below the surface of the round section after each of a series of reductions.

The effects of starting diameter and original hardness upon the distribution of the final hardness are reported.

IN a recent study of the relation between degree of cold working and the annealing temperatures of iron-tungsten alloys, the location of the tested section relative to the surface of the worked metal appeared from the start to be an important factor.

The present investigation is concerned with the study of this factor as related to certain other conditions which seemed likely to influence it.

VARIABLES CONCERNED

It is obvious that the shape and dimensions of the material must be considered as important factors in determining the hardness throughout the cold-worked section. The present study is concerned only with round sections. These sections were cut from rods reduced by cold swaging from a fixed starting diameter.

The starting diameter is obviously another factor to be considered in the distribution of hardness throughout the cold-worked section. The report includes data from three starting diameters.

Additional variables are to be found in the physical properties of the metal under observation. These would include hardness, ductility and other properties which might be determined individually.

A paper presented before the Eleventh Annual Convention of the society, Cleveland, September 9 to 13, 1929. Of the authors, who are members of the society, W. P. Sykes is metallurgical engineer, Cleveland Wire Works, incandescent lamp department, General Electric Co., Cleveland, and A. C. Ellsworth is associated with the Thompson Products Co., Cleveland. Manuscript received May 23, 1929.

STARTING MATERIALS

Copper, Armco ingot iron, and a carbon-free alloy of iron with 8 per cent tungsten were selected for this investigation. In the annealed condition these metals cover a moderately wide range in hardness. The Brinell hardness numbers of these materials before cold working were as follows: copper 50, Armco iron 80, iron-tungsten 120.

Since some of the surfaces to be tested were too small in dimensions to permit the use of the Brinell ball, the hardness measurements were made in all cases on the Rockwell B scale. As will be observed from the tabulated data, this results in a negative hardness number in the case of the annealed copper.

Copper rods 8 inches long and 0.500 inch diameter were turned from buss bar stock and annealed in an electric muffle furnace for three hours at 1290 degrees Fahr. (700 degrees Cent.).

In the case of the Armco iron three sets of rods were prepared for swaging. The diameters were 0.500 inch, 0.370 inch and 0.250 inch. These were turned from round stock 0.750 inch diameter, heated in a hydrogen atmosphere at 1830 to 1920 degrees Fahr. (1000 to 1050 degrees Cent.) for one hour and cooled in the furnace to about 570 degrees Fahr. (300 degrees Cent.) from 2 to 3 hours.

The iron-tungsten alloy was prepared from the mixed metal powders by sintering the pressed bars at 2640 to 2730 degrees Fahr. (1450 to 1500 degrees Cent.) for 3 hours in a hydrogen atmosphere and cooling to room temperature in about 15 minutes. From these bars, about 0.750 inch square, rods were turned 8 inches long and 0.500 inch in diameter.

It should be noted that an iron-tungsten alloy containing 8 per cent tungsten is not subject to the alpha-gamma change upon cooling. Moreover all of the tungsten present remains in solid solution during the cooling from an elevated temperature. Hence the cooling rate has no influence upon the hardness of this material.

COLD WORKING

As previously stated, the rods were swaged cold to a series of final diameters representing total reductions in area of the following percentages, 3, 7, 10, 13, 25, 50 and 75.

The Armco iron of 0.370 inch original diameter was worked by reductions of $3\frac{1}{2}$, $6\frac{1}{2}$ and $12\frac{1}{2}$ per cent, within limits of plus or minus $\frac{1}{2}$ per cent.

In all other cases the $3\frac{1}{2}$ -per cent draft was used. While the rods and dies were not artificially cooled during the swaging operation, both were at room temperature before starting, and the rods

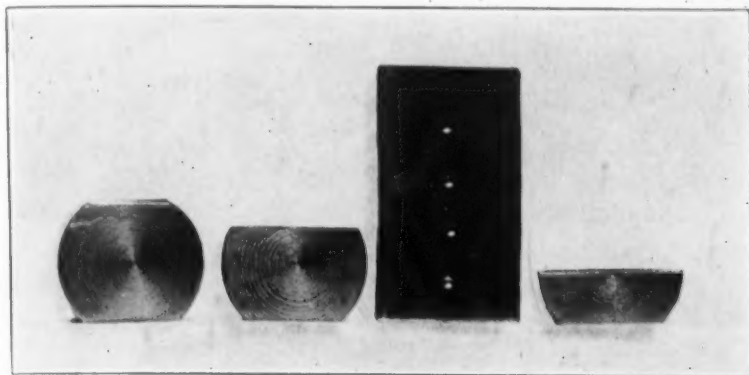


Fig. 1—Test Blocks Showing Sections at Various Depths Below Surface.

were immersed in cold water immediately after removal from the dies. Even after the $3\frac{1}{2}$ -per cent reduction, which required not more than five seconds, the rod was warm. This point is mentioned because it appears to be of considerable importance in the interpretation of the data. The rods after swaging to the desired diameters were machined with light cuts to the shapes shown in Fig. 1. During this operation the material was cooled with water to prevent heating as far as possible.

HARDNESS MEASUREMENTS

Plane surfaces for testing were cut longitudinally at depths, expressed in terms of the radius as $\frac{1}{8} R$, $\frac{1}{4} R$, $\frac{1}{2} R$, $\frac{3}{4} R$, and R . This last surface, R , is naturally a longitudinal section through the axis of the rod. A plane surface to serve as a base was cut on the opposite side and parallel to the surface for testing at a depth of $\frac{1}{4}$ of the radius.

Two specimens, 0.750 inch in length, were prepared for measurements at each of the five depths from the material as swaged to the desired diameter.

Five measurements were made upon each of the two specimens and the average of the ten readings recorded as the hardness number.

Table 1
Rockwell B Hardness of Armco Iron Reduced by 7 Per Cent Drafts in Swaging

7 Per Cent Total Reduction Depth of Tested Section Below Surface in Terms of Radius				75 Per Cent Total Reduction Depth of Tested Section Below Surface in Terms of Radius			
$\frac{1}{4}$ radius		1 radius		$\frac{1}{4}$ radius		1 radius	
75	76	74	73	93	92	90	92
73	75	75	75	93	92	92	93
75	75	74	74	95	94	93	92
73	73	73	75	93	93	92	94
76	74	75	75	94	94	92	92
Average				93.6	93	91.8	92.6

Table I is included to show the degree of uniformity encountered in these materials and is typical of the measurements as a whole.

DISCUSSION OF RESULTS

The curves in Fig. 2 give some idea of the relative rates of hardening in the three materials during the progress of cold working up to a total reduction of 25 per cent. After this amount of cold swaging the Rockwell "B" hardness number has been raised by 77 points in the case of copper. The Armco iron has increased 48 points and the iron-tungsten 30 points. Of this total increase in hardness a large part has already been brought about during the first 3 per cent reduction. Expressed in percentages of total increase the figures at 3 per cent are as follows: copper 65, Armco iron 71, and iron-tungsten 90.

While the iron-tungsten, originally the hardest material, has numerically been hardened least by 25 per cent reduction, yet the greater part of this hardening has taken place during the first step in the swaging operation.

The relative rates of hardening at different depths are shown in Fig 3. The iron of 0.500 inch starting diameter has, after 25 per cent reduction, developed a hardness which is practically uniform throughout the section. The copper of the same dimensions and after an equal reduction, is still noticeably softer at the center than near the surface, as is shown in Fig. 4. The difference is even more noticeable after only 13 per cent reduction.

In some cases, the hardness of the outer section is slightly less than that of the center. This is especially true of the material which

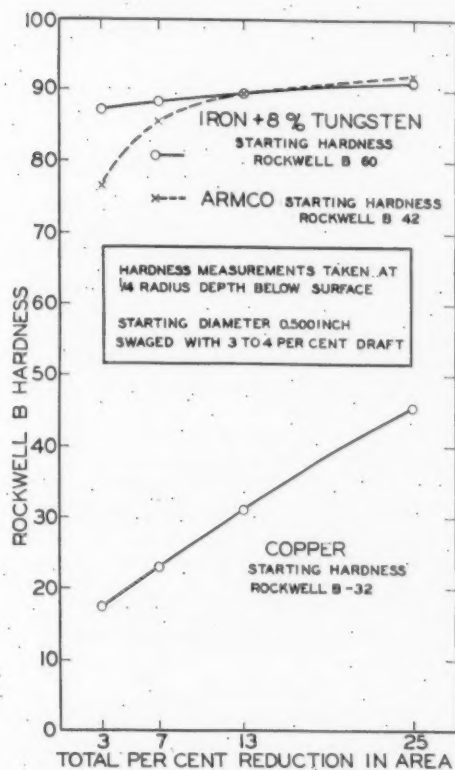


Fig. 2—Curves—Per Cent Reduction in Area versus Hardness at Constant Depth for Three Materials.

has been more severely worked. An explanation may be found in the heating of the outer portions of the rods during deformation.

To ascertain the extent of this effect some material was swaged in dies previously heated to 570 degrees Fahr. (300 degrees Cent.). This resulted in a marked softening in the outer portions, and the hardness throughout the section is plotted in Fig. 5 along with the hardness values obtained from a rod of like diameter swaged in unheated dies.

Similar curves for copper, swaged through dies at 212 degrees Fahr. (100 degrees Cent.) and through unheated dies are also shown in Fig. 5. The same effect is apparent, though the copper from the heated dies is softer throughout than that swaged cold, and the surface is still somewhat harder than the center.

INFLUENCE OF STARTING DIAMETER

The difference in hardness between the center and the surface

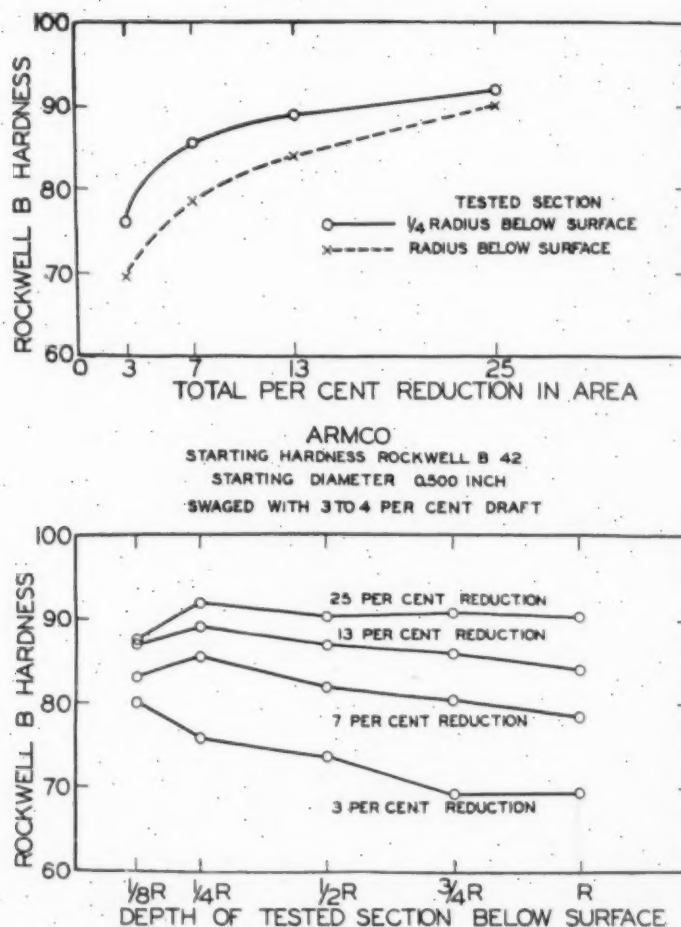


Fig. 3—Curves—Armco Iron Variations in Hardness with Depth Below Surface.

after a given reduction by cold swaging must be determined by the diameter as well as the physical properties of the material. An attempt is made in Fig. 6 to illustrate these relations. The ratio of the hardness at the center to that near the surface is designated by

$\frac{H_R}{H_{\frac{1}{8}R}}$. Obviously when the hardness is uniform throughout the section this ratio becomes unity.

The ratio is plotted against total reduction for the three materials with a starting diameter of 0.500 inch. In addition two smaller diameters of the Armco iron are included. Note that the iron of 0.250-inch starting diameter is of uniform hardness throughout after a reduction of but 3 per cent.

The iron of 0.370-inch diameter after 3 per cent reduction has

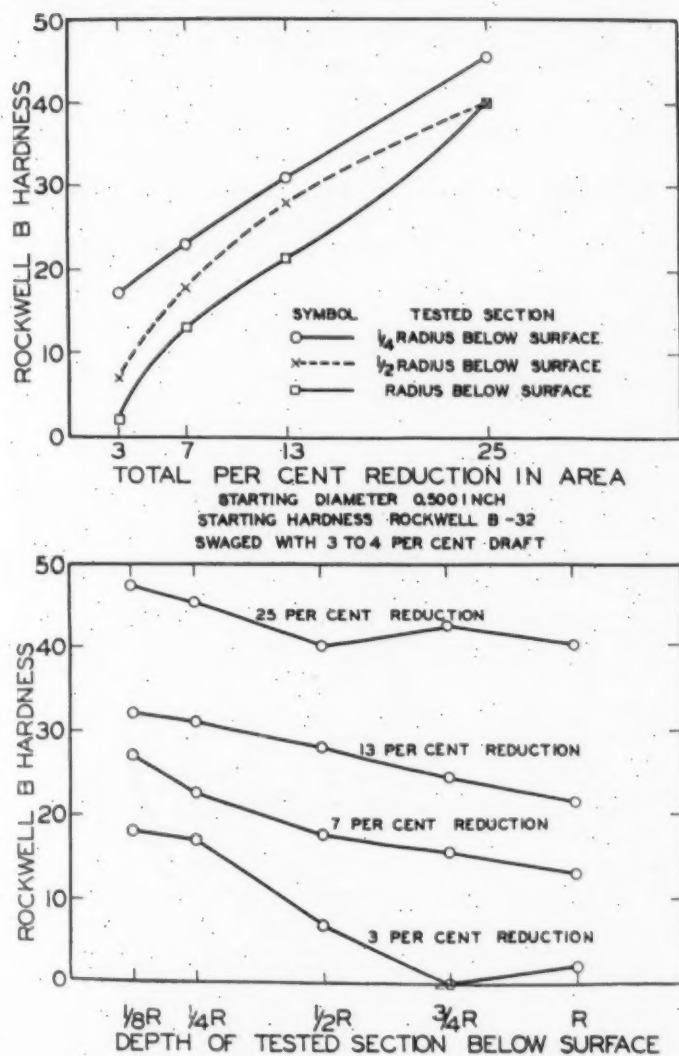


Fig. 4—Curves—Copper: Variations in Hardness with Depth.

a center to surface difference lying between that of the largest and smallest diameters.

The iron-tungsten alloy shows the least difference of the three materials of large diameter after a 3 per cent reduction, while in the copper the attainment of a uniform hardness proceeds most slowly.

INFLUENCE OF DRAFT, OR REDUCTION PER DIE

To ascertain the effect of the amount of reduction per die three

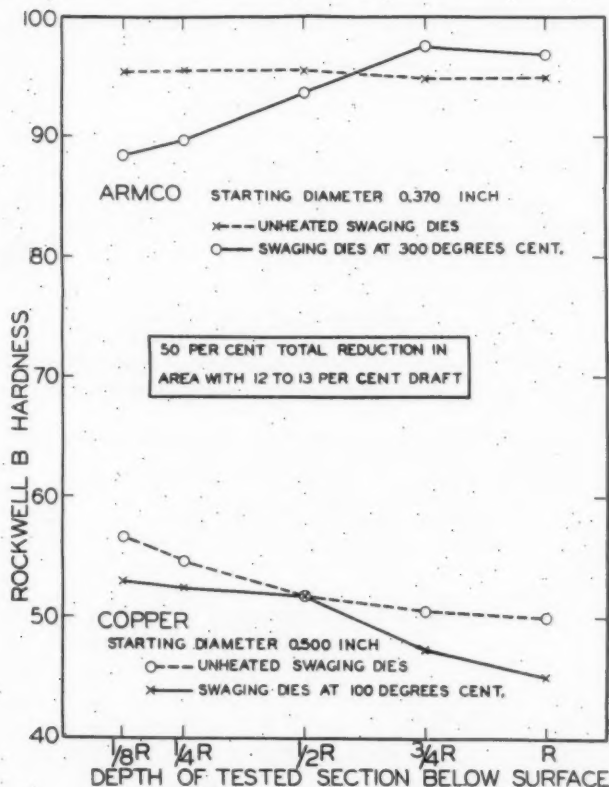


Fig. 5—Curves—Effect of Heated Swaging Dies on Distribution of Hardness Throughout Section.

sets of Armco iron rods were swaged by drafts of 3, 7, and 13 per cent respectively.

The resulting hardness measurements taken throughout the sections are listed in Table II. There are too many inconsistencies among these figures to warrant any conclusion. The low hardness throughout the section in the case of the iron reduced 25 per cent by 12-13 per cent draft is difficult to explain. These particular rods were not swaged at the same time as the others in this group and possibly the dies may have been previously heated by other hot swaging operations. Aside from this there is good agreement between the hardness values in the center sections for all three drafts.

Rods of a larger starting diameter might perhaps furnish data of a more positive nature in a study of this factor. A study of the distribution of tensile strength in hard drawn copper wire has been reported by Harris.¹ In this investigation various types of copper

¹Frank W. Harris, "Distribution of Tensile Strength in Hard Drawn Copper Wire." Technical Publication No. 93. Institute of Metals Division, American Institute of Mining and Metallurgical Engineers, 1928.

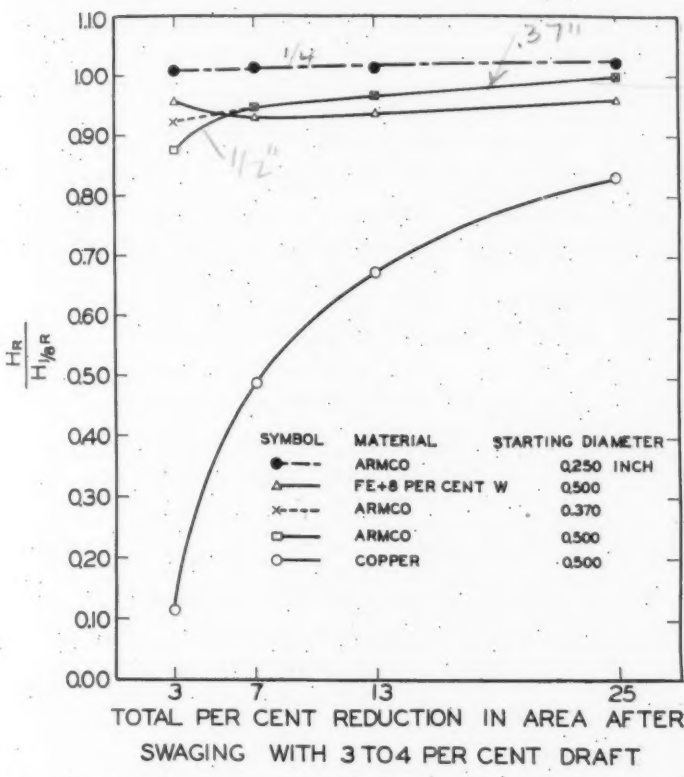


Fig. 6—Curves—Total Reduction by Cold Work versus Center to Surface Hardness Ratio.

Table II
Rockwell B Hardness of Armco Iron Reduced by Different Drafts in Swaging

Total Reduction (Per Cent)	Finished Diam. In.	Depth of Tested Section Below Surface in Terms of Radius				
		$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1
Swaged by 3 Per Cent Drafts						
3	0.364	78	78	77	75	72
7	0.358	..	83	83	80	78
13	0.345	..	86	87	85	83
25	0.320	..	87	88	88	87
Swaged by 7 Per Cent Drafts						
7	0.358	74	75	76	74	74
13	0.345	85	85	84	84	83
25	0.320	..	94	95	95	88
50	0.260	..	95	96	97	96
75	0.185	..	93	94	93	92
Swaged by 13 Per Cent Drafts						
13	..	..	87	85	84	83
25	..	..	77	78	81	81
50	..	..	96	96	96	95
Original Diameter = 0.370 Inch Original Hardness Rockwell B—40 to 44.						

Original Diameter = 0.370 Inch
Original Hardness Rockwell B—40 to 44.

rod and hard drawn wire were treated with nitric acid in such a manner as to remove successive layers of metal from the surface. The

treated material was then tested for tensile strength. This author states in his conclusion as follows:

"The results of the experiments show that the strength of hard drawn wire and commercial hot-rolled rod is by no means constant throughout the section. The 'skin' of the wire is, in general, below the average of the whole. There appears to be a point of low strength at the axis, but the method of testing adopted does not permit complete exploration of this area.

"The region of the highest strength appears to be in a zone near the core.

"Commercial hot-rolled rod shows a variance of strength throughout the section, being lowest at the outer zone and highest at, or near the core. Annealed rod, however, is almost uniform throughout.

"The effect of one draft on commercial soft copper is to raise the strength of the 'skin' above the average for the whole wire. Further drafts bring about the same conditions as before."

It seems likely that the method of working will be an additional factor in determining the distribution of hardness and tensile strength throughout the section.

SUMMARY

Of the three metals observed, that of original greatest hardness increases the least numerically in hardness during a reduction of 25 per cent by cold swaging. The greater part of this hardening has occurred during the first 3 per cent reduction.

The smaller the original diameter of the swaged rod the less the reduction required to produce uniform hardness throughout.

Uniform hardness throughout is more rapidly developed in a hard material than in a soft one. The factor of draft, within the range observed is less important than certain other conditions of working.

In any analysis of hardness distribution throughout the section of a worked metal it is necessary to recognize the effect of the heat developed during the process of deformation.

DISCUSSION

Written Discussion: By N. P. Goss, American Steel and Wire Co. Cleveland.

In 1927, Wassermann and Schmid, by means of X-ray spectrograms of the Debye type, and physical tests, proved that the core of extremely

hard drawn copper wires was stronger than the "skin." The X-ray spectrograms showed that the orientation of the grain fragments was much more regular at the core of the wire than at a point just below the surface of the wire. In fact, the spectrograms suggested that the "skin" of this extremely hard drawn copper wire had a kind of random orientation of the crystal fragments. Perhaps this variation of fiber structure would account in part for the lower Rockwell B hardness near the surface of the specimens which the authors (W. P. Sykes and A. C. Ellsworth) swaged rather severely.

Wassermann and Schmid did not use steel wires in their experiments, so it was necessary to test them in a similar manner, i. e., to see whether or not steel wires also possessed a "skin." Accordingly, some low carbon steel wire was drafted through wire drawing dies until it had a total area reduction of 99.5 per cent. The final diameter of this hard drawn wire was 0.025 inch. A specimen of this wire was prepared for X-ray analysis. The X-rays were reflected directly from the surface of the specimen as cold-worked. Fig. 1 of this discussion is the pattern obtained. The X-ray beam was polychromatic, and the X-rays were produced by a molybdenum target, and the tube potential was 35,000 volts. The specimen used to make Fig. 1 was etched in a 10 per cent solution of nitric acid in alcohol (nital), until it was 0.010 inch in diameter, and another X-ray spectrogram made. Fig. 2 shows the result. On comparing Fig. 1 and 2, it will be seen that Fig. 2 suggests a more regular orientation of crystal fragments, while Fig. 1 suggests a very irregular orientation of the grain fragments. This experiment confirms the work of Wassermann and Schmid. The irregular orientation of the crystal fragments near the surface of extremely hard wire may be due to: (1) Method in which the wire is worked, (a) swaged, (b) cold drawn, (c) forged, etc., (2) temperature, (3) speed of working (reduction per pass and linear speed).

It was of interest to me to determine, if possible, the thickness of this "skin," so a series of X-ray spectrograms were made of this extremely hard drawn wire, etched down to certain diameters. An X-ray spectrogram was made of the wire as drafted, and it was 0.025 inch in diameter. The second X-ray spectrogram was made after the specimen had been etched down to a diameter of 0.023 inch (Fig. 3).

No great change in the X-ray spectrogram could be observed. So it could, at least, be stated that the "skin" was more than 0.001 inch thick. A marked change was observed in the X-ray spectrogram when the specimen was etched down to 0.021 inch. In other words, this "skin" is about 0.002 inch thick. Fig. 4 is the X-ray spectrogram of this wire, when etched down to 0.021 inch.

Another thing of importance is the grain size. It has been found that metals composed of large grains resist grain fragmentation to a much greater degree than the fine-grained materials, when the drafting does not exceed 15 per cent area reduction.

When a metal having a fine grain structure is cold-worked, so as to

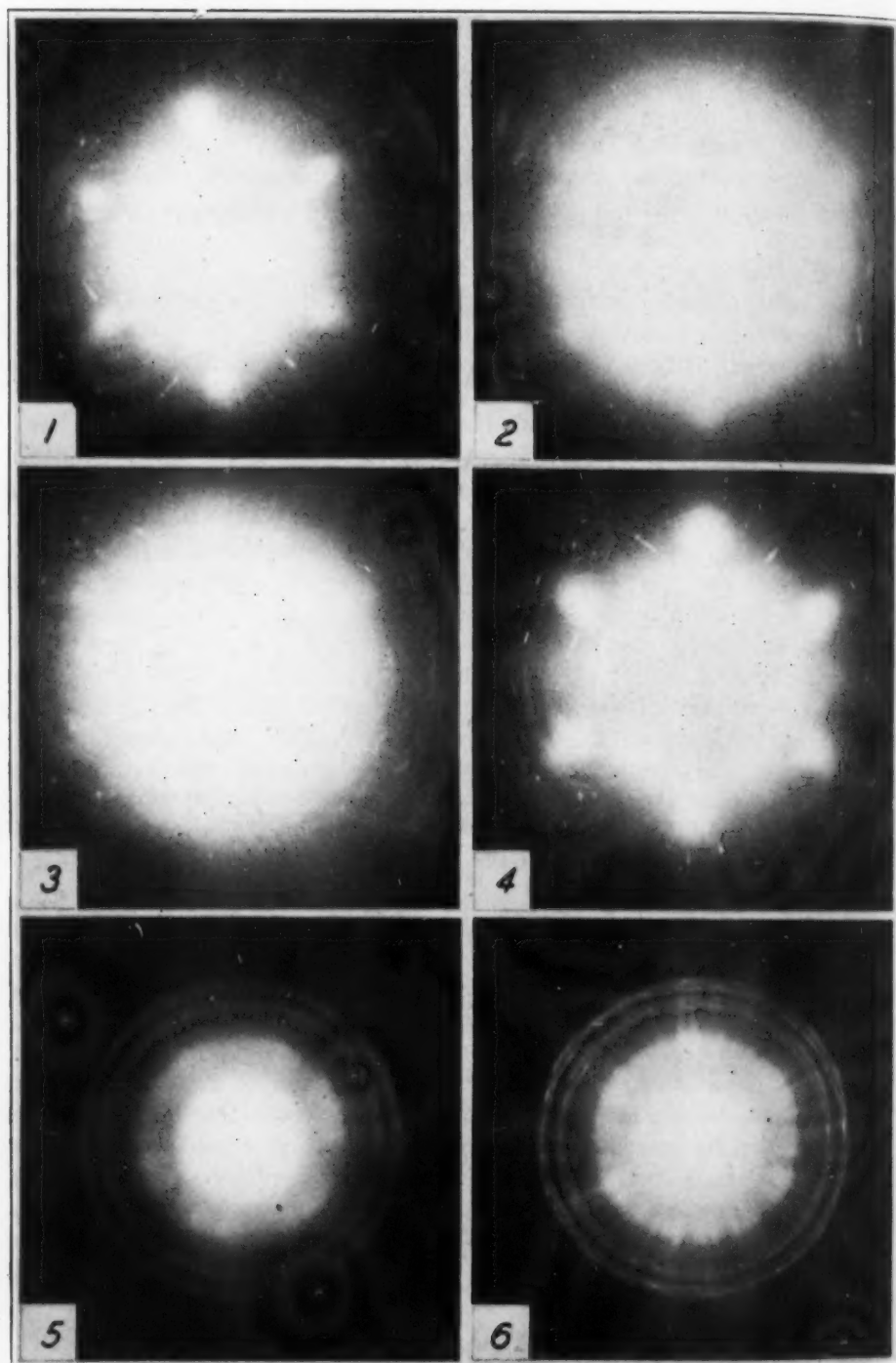


Fig. 1—Low Carbon Steel Wire, Drafted 99.5 Per Cent (0.375 to 0.025 inch). The X-rays were Reflected from the Surface of the Wire.

Fig. 2—Same as Fig. 1 but Etched to 0.010 Inch Diameter.

Fig. 3—Low Carbon Steel Wire, Drafted 99.5 Per Cent (0.375 to 0.025 inch). The Specimen Etched until 0.023 Inch Diameter, and X-ray Beam Reflected from Surface.

Fig. 4—The Specimen Used to Make Spectrogram Fig. 3 was again Etched until 0.021 Inch Diameter. Fig. 4 Shows Result when Diameter is reduced 0.004 Inch by Etching.

Fig. 5—X-ray Spectrogram of Screw Stock. The Specimen for X-ray Analysis was Cut from a Point just Below the Surface. This Screw Stock was 2 Inches Diameter.

Fig. 6—X-ray Spectrogram of Same Screw Stock, but Taken from Central Portion.

reduce the area 15 per cent, it was found that the grain fragments begin to line up so as to have the (1 1 0) planes lie in the direction of working. This alignment of grain fragments is due to slip and rotation on (1 1 0) planes. In very fine-grained material, preferred orientation can be detected when the area reduction is only 5 per cent. Extremely large grains are not completely fragmented when the area reduction is as much as 15 per cent. An area reduction of 5 per cent would only show a slight grain fragmentation. This shows how important grain size is when the material is to be cold-worked.

If a certain metal should be composed of extremely small grains and extremely large ones, and cold-worked, so as to reduce its area 15 per cent, the small grains would not only be fragmented but orientated in a definite manner, while the large grains would only be partially fragmented. Such a material would show considerable variation in hardness, before and after the cold working.

Figs. 5 and 6 show the variation in grain fragmentation in cold-worked screw stock. The surface section has received greater grain fragmentation than the central section. This indicates that the grains near the center of the screw stock were slightly larger than those near the surface.

Written Discussion: By J. D. Armour, metallurgist, Union Drawn Steel Co., Beaver Falls, Pa.

The authors have chosen a very interesting subject for investigation although it is one that is affected by so many variables that misleading conclusions are apt to be drawn unless great care is taken in interpreting results. Some of the conclusions in the present paper appear to the writer to be unwarranted.

They have shown in their investigation that of three metals observed copper showed the greatest increase in hardness as a result of 25 per cent reduction by cold swaging. Armco iron showed the second largest increase, and an iron-tungsten alloy, containing 8 per cent tungsten, increased the least. In their summary they infer that this was due to the fact that the copper showed the lowest starting hardness, Armco iron second, and the iron-tungsten alloy the greatest starting hardness.

It is the writer's opinion that the relative malleability of the three metals observed affected their behavior under cold swaging to a larger degree than their difference in starting hardness. In other words, their results show that of the three metals observed copper has the greatest capacity for work hardening under cold swaging, Armco iron second, and the iron-tungsten alloy the least. As a natural consequence of their relative malleability the iron-tungsten alloy would attain uniform hardness more rapidly than the Armco iron and the Armco iron more rapidly than the copper. The authors also state in their summary that "uniform hardness throughout is more rapidly developed in a hard material than in a soft one," and the writer believes this conclusion is also unwarranted. Metals with both greater and less starting hardness than this iron-tungsten alloy could be chosen which would behave under cold swaging more nearly like the Armco iron or copper.

Of the three materials investigated, two are comparatively pure metals while one is a solid solution alloy. Solid solution alloys in general have less capacity for cold deformation and are hardened more by a given amount of cold deformation than the pure solvent metal. Grain size also affects the capacity for cold deformation; the coarse grain having the greatest capacity for deformation. This fact is made use of in processing certain grades of steel wire which are to be used for cold upsetting, the wire being normalized at a high temperature to promote coarsening of the grain.

Aside from grain size, the capacity for cold deformation in steel is greatly affected by its structure. The effect of structure on the capacity for work hardening in steel is illustrated by the following experiment which was made in the laboratories with which the writer is connected.

A piece of 11/16-inch round 0.35 per cent carbon steel which had a Brinell hardness of 146 in the as-rolled condition showed a Brinell hardness of 187 after a 15 per cent reduction in area by cold drawing; an increase of 41 points. A piece of the same bar heat treated to a Brinell hardness of 192 before cold drawing showed a Brinell of 212 after cold drawing, an increase of 20 points. A third piece of the same bar was heat treated to 223 Brinell and after cold drawing it showed a hardness of 235 or an increase of 12 points. A fourth piece was heat treated to 255 Brinell and after drawing showed a hardness of 248 Brinell, a decrease of 7 points. A fifth piece heat treated to 293 Brinell showed a hardness after cold drawing of 277, a decrease of 16 points. These results indicate that when steel is hardened by heat treating it reduces its capacity for hardening by cold work correspondingly.

The author's observations on the effect of heated swaging dies are very interesting. In the case of Armco iron they found that by using dies heated to 570 degrees Fahr. (300 degrees Cent.) the outer section of the wire was softer than the center. This is more or less contrary to what might be expected.

Jeffries and Archer in their book "The Science of Metals" report results of tests on Armco wire which show that cold drawing at a temperature of 525 degrees Fahr. (275 degrees Cent.) gave a tensile strength of 111,000 pounds per square inch, against 85,720 pounds per square inch on the same wire drawn at room temperature. No hardness results are shown but it would naturally follow that the material showing the highest tensile strength would have the greatest hardness. The conditions in the two experiments were not exactly parallel and it is to be hoped that Sykes and Ellsworth will continue their investigation along this line.

Written Discussion: By Thomas D. Taylor, metallurgist, Bliss and Laughlin, Inc., Harvey, Ill.

After carefully reading this most interesting and welcome paper devoted to the distribution of hardness produced by cold working, it is found that the items presented in the summary and borne out by experimental fact, very closely parallel the writer's experience, having con-

stantly studied this same fact in the cold drawing of practically all of the steels included in the S. A. E. specifications as well as Armco ingot iron from hot-rolled sections.

It has been the writer's contention that the uniformity of hardness produced by cold working depended largely upon the starting materials metal flow ability, size of section and the thermal condition at the time of subjection. It is apparent that the softer characterized material possesses a greater metal flow ability, and is less resistant to an operation such as cold working. As this resistance becomes less, so would we expect the degree of hardness to approach the original hardness as a limit, as we proceed in test from the surface to a radius depth, and from a maximum to a minimum degree of draft. As this resistance is increased either by greater hardness of starting material or increased draft and speed of operation in softer materials, the degree of hardness at radius depth and at surface becomes one and the same. In other words, the harder the material, the smaller the draft required to develop a uniform condition of hardness throughout the section.

This fact was very pronounced in the study of certain alloy steels which had been heat treated to a Brinell hardness of 302 to 332 before cold drawing, and comparing it to the cold drawing of an open-hearth steel, carbon 0.08 per cent maximum.

Written Discussion: By Paul F. Mumma, department of metallurgy and research, National Tube Company, Pittsburgh.

The work reported in this paper is interesting and valuable to anyone concerned with the manufacture or use of cold-worked metallic shapes. In the production of commercial bar stock, however, the cold working is usually done by rolling or drawing rather than by swaging; and it appeared possible that when using this different method of cold working the penetration of the hardening effect toward the center of a bar, and the resulting hardness distribution from the outside to the center of the bar, might be markedly different from that reported by the authors for cold-swaged sections.

In order to determine the facts in the case, a series of specimens similar in form to those used by the authors was prepared from a solid round bar of hot-rolled 0.08 per cent carbon steel which had been cold drawn in one pass from 0.875 to 0.828 inch in diameter—a reduction in area of approximately 10 per cent. This stock had an initial hardness of B56. Rockwell tests on the cold-worked specimens gave the results depicted by curve No. 1 in Fig. 1 of this present discussion. For comparison, curves Nos. 2 and 3 were plotted from data given in Table II of the original paper and show the effect of single drafts of 7 and 13 per cent respectively on 0.370 inch diameter Armco iron specimens. Presumably a 10 per cent draft would have given intermediate results.

It appears that in our tests the effect of the larger starting diameter has been compensated by a somewhat higher initial hardness, so that the 10 per cent reduction by cold drawing on the 0.875 inch diameter 0.08 per cent carbon steel has resulted in about the same final hardness as

would be expected on the 0.370 inch diameter Armco iron after a single draft of 10 per cent by cold swaging. The distribution of the hardness produced by cold drawing seems to be equally as uniform as that obtained by cold swaging.

It is consoling to find that in sections cold-worked by as little as 3 per cent reduction the hardening and strengthening effect penetrates to the center of the section and that contrary to the popular notion the

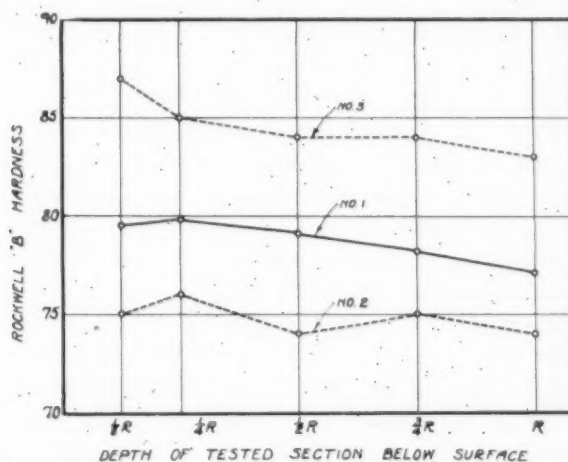


Fig. 1—Rockwell Tests on Cold-Worked Specimens. Curve No. 1—Variation in Hardness with Depth Below Surface of 0.08 Carbon Steel Reduced 10 Per Cent by Cold Drawing from 0.875 Inch Initial Diameter.

Curve No. 2—Variation in Hardness with Depth Below Surface of Armco Iron Reduced 7 Per Cent by Cold Swaging from 0.370 Inch Initial Diameter. (Sykes and Ellsworth).

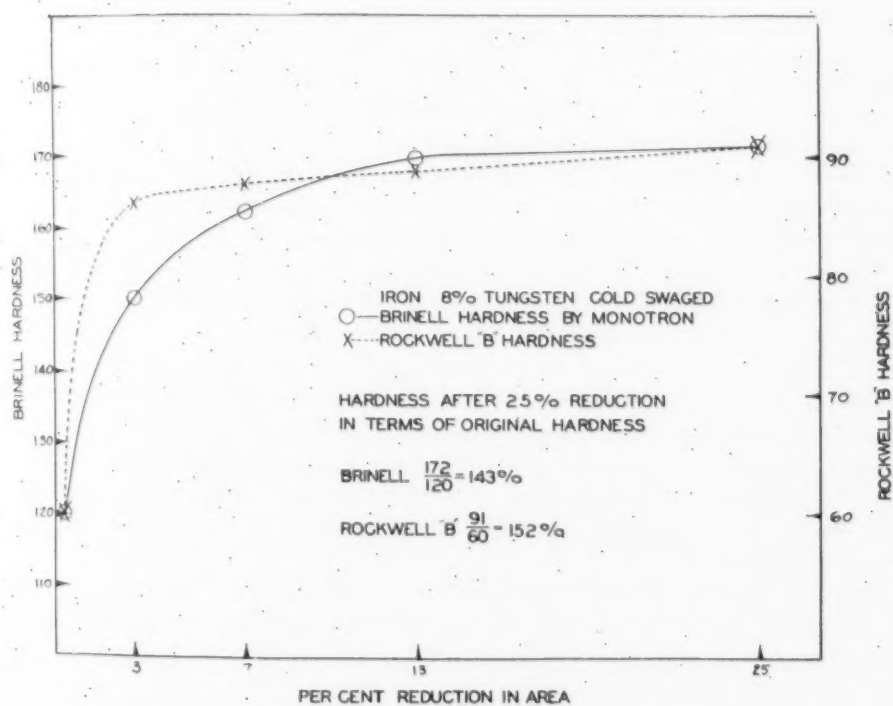
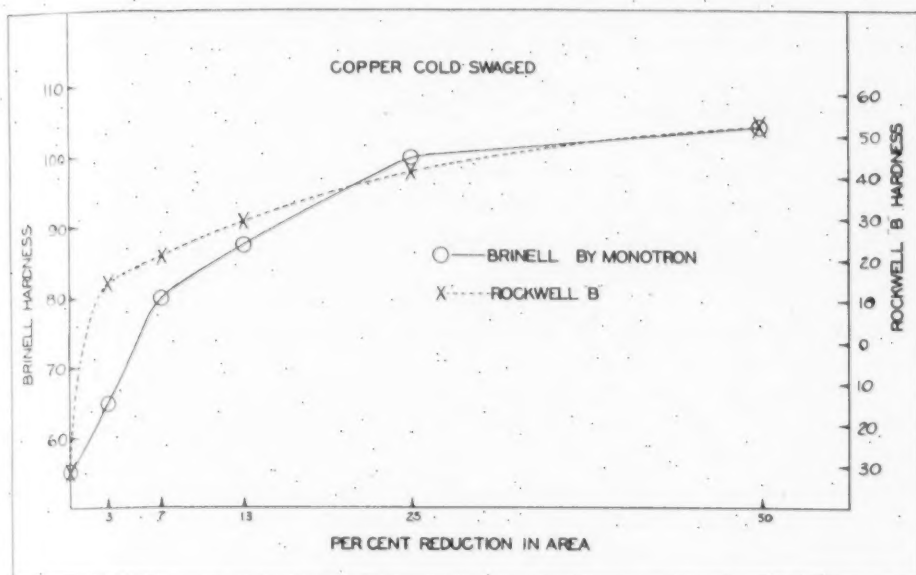
Curve No. 3—Variation in Hardness with Depth Below Surface of Armco Iron Reduced 13 Per Cent by Cold Swaging from 0.370 Inch Initial Diameter. (Sykes and Ellsworth).

observed increase in sectional strength is not concentrated in a relatively thin outside shell or "veneer", where its usefulness may be entirely lost by such operations as threading or turning to some smaller diameter.

Authors' Closure

The authors are gratified to learn of the general interest in the problem so briefly dealt with in the paper, and appreciate the confirmatory data offered in the discussions. They consider that the results so far attained should be regarded mainly as pointing a way to methods for further and more illuminating investigations in this field.

In order to draw a complete picture such studies should be made upon materials reduced by drawing and also by rolling. Sections larger than 0.500 inch in diameter would seem to be best suited for following the progress of hardening, especially in the range of very small reductions. As has been intimated, the factor of temperature is an important one and at the same time difficult of close control, especially in sections of appreciable thickness.



The distribution of temperature throughout the section goes hand-in-hand with the distribution of hardness resulting from working. The X-ray data offered by Mr. Goss suggest a profitable application of this method in such a study.

It would seem that his final conclusion regarding the original difference in grain size between the surface and the central portions of the screw stock are not entirely warranted.

The diffraction pattern from the central portions undoubtedly indicates the larger grain size. The exterior portions have of necessity suffered fragmentation to a greater degree by the drawing operation, and this alone might produce the continuous lines of the pattern from the outer portions. This is especially likely because of the relatively large diameter and small amount of reduction involved in this case.

The comments of Mr. Armour are especially welcome. Obviously, from the data which he presents, the rate of hardening is influenced by factors other than that of starting hardness.

The "cause" of the original hardness is no doubt a factor which must be considered in connection with rate of hardening or capacity for work hardening. The authors stated in the introduction that additional variables are to be expected in certain physical constants of the metal under consideration. Undoubtedly the term "malleability" should have been included at this point.

In regard to the softening of the outer portions of the iron swaged in heated dies, it must be noted that while the dies were at 300 degrees Cent. (570 degrees Fahr.) immediately before placing in the swaging machine, they doubtless had cooled to some extent before the iron rods were inserted in the dies. Furthermore, during the swaging operation, the die is in contact with a given portion of the rod for only a very short time. As a result, the iron rod even at its surface is certainly not heated to a temperature of 275 or 300 degrees Cent. (525 or 570 degrees Fahr.).

In the same reference cited by Mr. Armour is a curve of tensile strength versus temperature for annealed Armco iron wire. This indicates a considerable lower strength at 100 degrees Cent. than at 200 or 250 degrees Cent. It is probable that the iron rods under discussion in the present paper were actually heated at the surface to a temperature not above 100 degrees Cent. This no doubt accounts for the relatively softer outer portions.

Hardness measurements on some of the materials were made with the Monotron tester some time after the original data was compiled. These tests were made with a 1/16-inch steel, impressed to a depth of 15/5000 inch.

A comparison of the Rockwell B and Brinell hardness numbers obtained with the Monotron shows decided differences in the hardness increases produced by the first stages of reduction. The accompanying curves clearly illustrate this difference.

Note that the hardness as measured by the Rockwell B scale increases at a much higher rate in the early stages of working than that shown by the Monotron scale. After a moderate amount of hardening has taken place, the two systems of measurement agree very closely.

CONDITIONS NECESSARY FOR BLISTERING OF METAL DURING PROCESSING

BY DR. ANSON HAYES

Abstract

This paper points out two facts which have not generally been recognized in considering the causes of blistering of sheet metal. The first one is that the pressure required to raise a blister is inversely proportional to the radius of the curvature of the lamination in the sheet. The second is that in the pickling process the pressures which are responsible for the penetration of hydrogen during the pickling process are due to the surface tension of the pickle liquor during the time that the bubbles of hydrogen are quite small.

INDICATIONS based on observations, which many people have made, point to the correctness of the following statement:

The fundamental cause of blistering of various metals during processing is that gases collect in voids or laminations. The pressures required to cause blistering in such defects can be rather easily calculated.

The purpose of the present discussion is to make a treatment of the conditions necessary for blistering of ferrous materials under the conditions which are prevalent in annealing and pickling of sheet metal in particular.

GASES

In the normalizing furnace, blistering is ascribed either to hydrogen or to carbon monoxide. The carbon monoxide presumably results from the reaction between carbon and iron oxide. As will be shown later, pressures which under suitable conditions may develop by such a reaction are tremendous. The part which hydrogen plays in the blistering during annealing is due largely to the fact that residual hydrogen from the pickling process is retained with laminations in the metal, and also that the rise in temperature in the normalizing furnace increases the gas pressure and decreases the yield point.

A paper presented before the Eleventh Annual Convention of the society held in Cleveland, September 9 to 13, 1929. The author, Dr. Anson Hayes, member of the society, is director of metallurgical research, American Rolling Mill Company, Middletown, Ohio. Manuscript received June 7, 1929.

In the pickling process, the blistering which results is largely attributed to hydrogen penetration. It is safe to say that the two gases—hydrogen and carbon monoxide—do play the important roles in the blistering which results in the annealing treatment, and that hydrogen is largely responsible for the blistering which results in the pickling process.

VOIDS

The following considerations serve to show the reason for the association of blistering with the presence of voids or laminations.

In Fig. 1, B, is shown a diagrammatic representation of a lamination which is nearer one sheet surface. Such a lamination has dif-

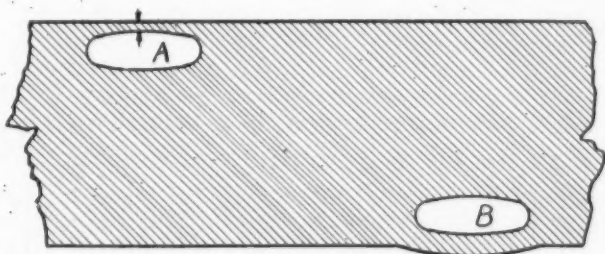


Fig. 1—Diagrammatic Representation of a Lamination Near One Sheet Surface.

ferent radii of curvature at different points on its surfaces. Because the radius of curvature is usually greatest for the surfaces of the laminations, which are parallel with the planes of the sheet surfaces, and since it is these surfaces which will deform at the lowest pressures of the gases, it will prove convenient to consider the surface of the lamination of Fig. 1, B, which is nearest to the lower sheet surface.

Consider a spherical shell (see Fig. 2) whose wall thickness is small as compared to the radius of the shell. The pressure of gas inside the sphere necessary to produce a stress in the direction of a tangent to its surface, equal to the yield point of the metal in the shell, may be obtained by computing the total force exerted on the area of any great circle of the sphere. For pressures of gases inside the sphere, this is the force tending to break the sphere into halves. It is the tensional stress on the metal shell at any point.

If " r " is the radius of the sphere, " t " is the thickness of the shell, and " y " is the yield point of the metal, the tensional force along any great circle on the circumference of the sphere, which is

equal to the yield point of the shell, is given by $2\pi r y t$; the area of a great circle is given by πr^2 ; and the pressure of gases in the sphere necessary to reach the yield point is therefore

$$\frac{2\pi r y t}{\pi r^2} \quad \text{or} \quad p = \frac{2\pi r y t}{\pi r^2} \\ \text{which reduced to } p = \frac{2y t}{r} \quad (1)$$

Equation (1) brings out the fact that the larger the radius of curvature of a lamination, the lower the gas pressure within it which

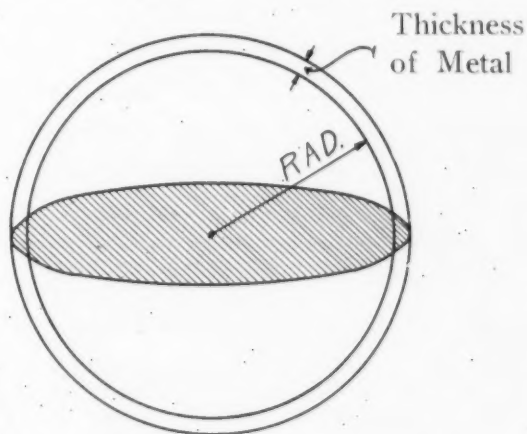


Fig. 2—Diagrammatic Representation of a Spherical Shell.

is required to reach the yield point of the metal between the lamination and the surface of the sheet for a given metal and wall thickness.¹

The condition for the formation of a blister is obviously that

$$p > \frac{2y t}{r} \quad \text{or that } p r > 2y t \quad (2)$$

If a lamination is near the surface of the metal, the formation of a blister accompanies the permanent deformation of the metal which lies between the lamination and the surface of the metal upon which the blister is formed. This deformation may be assumed to be due to the accumulation of gas at a sufficient pressure in the lamination to exceed the yield point of the metal for the radius of curvature and wall thickness which will involve the least pressure.

¹Equation (1) should not be used for shell thickness more than one-tenth the radius of curvature. However, the reasoning involved in its use is qualitatively correct to higher values of this ratio.

Equation (2) indicates that as "r" becomes very large, as would be the case for a flat lamination, that "p" becomes very small. The extent to which the surface of the metal may be raised is largely determined by the shortest dimension of the lamination in a direction parallel to the metal surface. This is true since this dimension of the lamination will determine the radius of curvature of the shell of the blister when it has been raised a given distance above the original surface of the metal.

To summarize the significance of the relation shown in equations (1) and (2), laminations must have radii above a certain limiting value, or pressures sufficiently high to exceed the yield point of even very thin metal will not be possible.

Some numerical illustrations of values of "p" which are required to reach the yield point of the metal for various sized inclusions will assist in showing the significance of this. Consider a lamination whose upper surface is 10^{-3} inches from the sheet surface. Assume the radius of curvature for this same surface of the lamination to be 10^{-2} inches before deformation has started. If the yield point of the metal is assumed to be 30,000 pounds per square inch, Equation (1) gives

$$p = \frac{2 \times 30,000 \times 10^{-3}}{10^{-2}} = 6000 \text{ pounds per square inch.}$$

If the radius of curvature is taken as 10^{-1} inches

$$p = 600 \text{ pounds per square inch.}$$

and if it be assumed to be 1 inch

$$p = 60 \text{ pounds per square inch.}$$

Since in Equation (1) "p" is the pressure necessary to set up deforming stresses equal to the yield point of the metal, these results may be stated as follows:

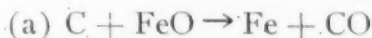
For a lamination with wall thickness of 10^{-3} inches and an upper surface with a radius of curvature of 10^{-2} inches, blistering will start when gas has collected in the lamination at a pressure of slightly above 6000 pounds per square inch. If the radius of curvature is 10^{-1} inches, 600 pounds pressure will be required; and for a 1-inch radius of curvature, only 60 pounds per square inch is needed.

Since for greater radii than these smaller pressure would be required to start deformation, the values of "r" may be considered

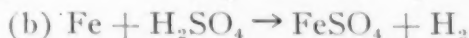
those at which deformation would stop for the pressure given in each case.

SOURCES OF GASES WHICH MIGHT PRODUCE PRESSURES SUFFICIENTLY HIGH FOR BLISTER FORMATION

The gases which produce the necessary pressures are those which are produced through chemical reactions within the metal or upon its surface during processing. One of the reactions which will be discussed is



The other is



Reaction (a) may take place during annealing if the values for the concentration of carbon and of iron oxide are above those which represent equilibrium conditions for this reaction, while reaction (b) is that which takes place in pickling. The pressures which reaction (a) can produce at temperatures near that of the room, if the assumption is made that it proceeds to equilibrium, may be calculated from the free energies of the compounds, FeO and CO. The pressures which reaction (a) can produce at temperatures near that of the room if the pure phases, C and FeO, are present can be determined if the assumption is made that the reaction proceeds to build up the equilibrium pressure. These pressures may be calculated from the free energies of the compounds, FeO and CO. Placing the respective standard free energies of the formation of the various compounds, reaction (a) gives

$$\text{O} - 64192 = \text{O} - 32510 + \Delta F$$

or

$\Delta F = -31682$ calories where ΔF is the free energy change accompanying the reaction per gram molecular weight of carbon monoxide formed.

Since the equilibrium constant for reaction (a) may be written $K = p_{\text{CO}}$, where K is the equilibrium constant for the reaction; and p_{CO} is the highest pressure of carbon monoxide which the reaction may produce; and since also

$$-\Delta F = RT \ln K = RT \ln p_{\text{CO}} \quad (3)$$

where the ΔF , K , and p_{CO} have the significance already given, and where R is the molal gas constant and T the absolute temperature.

Placing $T = 298$ degrees absolute; $R = 1.99$ calories; and using the value $-\Delta F = 31682$ calories as obtained above gives

$$\ln p_{co} = \frac{31682}{1.99 \times 298} \text{ where } \ln p_{co} \text{ is the natural logarithm}$$

or

$$\log p_{co} = \frac{31682}{2,303 \times 1.99 \times 298} = 23.2 \text{ for the common logarithm}$$

from which

$$p_{co} = 1.6 \times 10^{23} \text{ atmospheres.}$$

This enormous pressure indicates that whether or not blistering will be caused by this reaction will be largely determined by the concentrations of C and FeO in the metal and by the rate at which carbon monoxide is formed and the rate at which it diffuses at the pressures under which it is being formed. Since reaction (a) is endothermic, the equilibrium would shift as the temperature is lowered so as to allow higher concentrations of FeO and C to produce a given pressure of CO.

Due to the fact that metal is poured in the liquid condition, that is at higher temperatures, and is processed in the solid condition, at temperatures considerably below the melting point, reaction (a) would not be expected to proceed in the direction necessary for the production of carbon monoxide at these lower temperatures. However, there are in extreme cases the possibilities of segregation of impurities during solidification and later changes in the relative positions of such constituents during the rather extreme working processes through which the metal must go, that may offer possibilities of bringing together FeO and C at such concentrations as to make possible the formation of carbon monoxide from FeO and C.

BLISTERING DURING THE PICKLING PROCESS

There are a number of peculiar theories abroad in the land in regard to the mechanism by which hydrogen penetration of metal takes place during the pickling process. One of the most common among them is that as hydrogen is formed, it is in the atomic form and in this form it passes readily through the metal. This theory continuing on its way assumes that diatomic hydrogen forms, and since the metal is not permeable to hydrogen, this diatomic gas collects in such places and forms the blisters. The explanation of the

rather important mechanism by which the hydrogen penetrates the metal until the lamination is encountered rather than to form diatomic hydrogen gas at the metal surface is lacking.

A treatment of the effects of surface tension on hydrogen in small bubbles at the interface between the pickle liquor and the metal

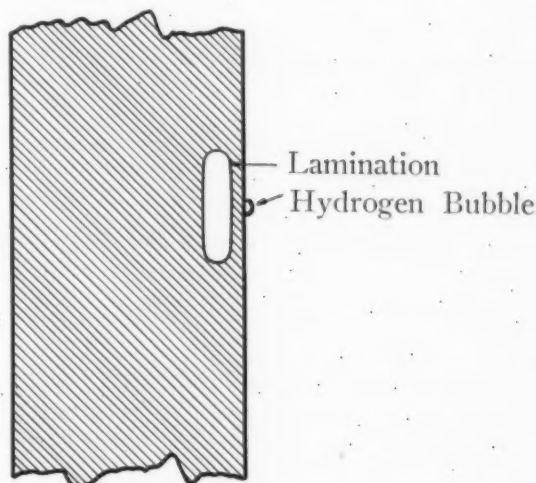


Fig. 3—Diagram Showing Hydrogen Bubble on Metal Surface.

surface makes the foregoing explanation complete. It does this by showing from what source pressures sufficiently high to cause hydrogen penetration may arise.

A treatment of the pressures upon the hydrogen within a hydrogen bubble, due to the surface tension of the pickle liquor, may be made in a manner quite similar to the treatment made for the calculation of the pressures within a lamination required to reach the yield point of the metal covering the lamination. If instead of the yield point of the metal and its thickness, as shown in Fig. 2, we consider the surface tension of the liquid we get

$$p = \frac{2\pi r\gamma}{\pi r^2} \quad (4)$$

Where "r" is the radius of the hydrogen bubble and "γ" is the surface tension, this equation reduces to

$$p = \frac{2\gamma}{r} \quad (5)$$

which is exactly similar to Equation (2) if " γ " is replaced by " yt ". If " γ " is in dynes per centimeter and " r " is in centimeters, " p " will be in dynes per square centimeter.

For a bubble 10^{-6} centimeter radius and in a pickle liquor whose surface tension is 72 dynes per centimeter, Equation (5) gives

$$p = \frac{2 \times 72}{10^{-6}} = 144 \text{ by } 10^6 \text{ dynes per square centimeter}$$

or

140 atmospheres which is equivalent to 2100 pounds per square inch.

For a bubble with a radius of 10^{-5} centimeters, a pressure of 210 pounds results. By use of Equation (1) $p = \frac{2yt}{r}$, the value

of " r " for a lamination in a certain location can be calculated for the condition that the pressure of 210 pounds per square inch is just sufficient to start a blister.

Assume, for example, that the thickness of metal between the surface and the lamination is 10^{-3} inches, and that the yield point of the metal is 30,000 pounds per square inch, for a wall thickness of 10^{-2} for the lamination, and assuming a value of " r " = 10^{-5} centimeters for the hydrogen bubble, a value for " r " of the lamination is 2.86 inches.

The significance of these values may be more clearly shown by the following statement:

The pressure of hydrogen within the bubble has changed from very high values at the time of its formation to the lower value of 210 pounds per square inch when the radius of the bubble is 10^{-5} centimeters. For example, when the radius of the hydrogen bubble was 10^{-6} , the pressure was 2100 pounds per square inch; and when the radius was 10^{-7} centimeters, the pressure was 21,000 pounds per square inch.

A very interesting deduction can be made from Equations (1) and (3) in regard to the ratio which must exist between the radius of curvature of a lamination at a certain position with relation to the metal surface, and the radius of the hydrogen bubble in which the hydrogen pressure will be high enough to force hydrogen into the metal surface with sufficient pressure to start a blister from such a lamination.

Equation (1) $p_1 = \frac{2yt}{r_1}$ gives the necessary pressure " p_1 "

within the lamination whose radius of curvature for the surface next to the metal surface is " r_1 " and where " y " is the yield point and " t " the thickness of the shell next to the surface.

Equation (3) $p_b = \frac{2\gamma}{r_b}$ gives the pressure " p " produced within a hydrogen bubble of radius " r_b " at the surface of the metal and in a pickling liquid whose surface tension is " γ " (gamma).

If equilibrium is approached between the hydrogen pressure within bubbles whose radii have a value " r_b " and the gas pressure within a lamination

$$p_1 = p_b = \frac{2yt}{r_1} = \frac{2\gamma}{r_b} \text{ or } \frac{r_1}{r_b} = \frac{yt}{\gamma} \quad (6)$$

In Equation (6) the quantities " yt " and " γ " must be expressed in corresponding units.

If a lamination is at a distance of 10^{-2} inches from the surface of metal whose yield point is 30,000 pounds per square inch, and if the surface tension of the pickle liquor is assumed to be the same as that of water at room temperature, Equation (6) gives

$$\frac{r_1}{r_b} = \frac{30,000 \times 10^{-2} \times 453 \times 980}{72 \times 2.54} = 7.3 \times 10^5 \quad (7)$$

where 453 is the factor for converting pounds to grams, 980 grams to dynes, and 2.54 inches to centimeters. Molecular dimensions are of the order of 10^{-8} centimeters. There is, therefore, no significance to hydrogen bubbles with radii less than this value. Substitution of this value in (7) gives

$$r_1 = 0.007 \text{ cm.}$$

This indicates that a lamination 0.025 centimeter from the surface of the metal must be longer than 0.07 centimeter before blistering would be possible, even if pickled at room temperature. For bubbles 10^{-7} centimeters radius, laminations must be 0.07 cm.

CONCLUSIONS

Blistering during the pickling process is the result of hydrogen

pressures which are produced by the surface tension of the pickling solution. Pressures from this source are not large enough to blister small laminations except those near the surface.

Laminations at distances greater than 0.025 centimeter (10^{-2} inches) must have radii of curvature greater than 0.5 centimeter for blistering to occur.

Pressures which may be developed by the reaction



are very large. If the phases, FeO and C, exist in contact under such conditions, blisters from smaller laminations and at greater distances from the surface would result. Fortunately, such a condition does not frequently arise with present practices of manufacturing sheet metal.

ACKNOWLEDGMENT

The author hereby acknowledges assistance from F. G. Norris in preparing the figures, and from J. H. Nead and R. J. Kenyon in criticizing the paper.

DISCUSSION

C. T. PATTERSON: I think Dr. Hayes' hydrogen calculations would have been even more striking and impressive if he had carried the bubble size down to the atomic size because we presume that when hydrogen is evolved, as when sulphuric acid attacks iron, the first hydrogen formed is of atomic size, then later these large bubbles are formed by coalescing. That will give pressures that are very surprising.

E. E. THUM: Dr. Hayes' calculations are interesting to mathematicians, but American steel treaters and metallurgists are not generally very familiar with mathematics or physical chemistry. They may not be so resistant to the simple supposition that hydrogen is a metal and it alloys readily with iron. That seems to be sufficient to explain a great many phenomena of embrittling action and hydrogen penetration.

Just what is the true nature of alloying—what causes hydrogen to enter into the space lattice with iron—is just as mysterious as what causes gold and lead when pressed together to interpenetrate. Or, for that matter, what causes carbon to be absorbed by steel from the surroundings in a carburizing pot.

Written Discussion: By George L. Kelley, Edward G. Budd Mfg. Co., Philadelphia.

It is still somewhat unusual in the solution of metallurgical problems to make use of physico-chemical methods of analysis. In most of the cases where this has been done before so much of the data has not been

available in definite form that the conclusions drawn were necessarily vague.

Dr. Hayes' paper furnishes us with an example in which this method has been applied with gratifying success. I shall hope that Dr. Hayes will find other opportunities to apply these interesting methods.

Author's Closure

In regard to the remark of Mr. Patterson, on page 534 of the paper, the calculation was made of a bubble size to 10^{-7} which shows a corresponding pressure of 21,000 pounds per square inch rather than 2100, and if we consider the bubble of molecular dimensions which would be of the order of 10^{-8} we would have 210,000 pounds per square inch rather than 21,000. Those values are shown in the paper.

In regard to the remarks of Mr. Thum, the thing that prompted me to make this mathematical discussion was the fact that hydrogen penetrates the metal and collects in the voids or laminations as molecular hydrogen at sufficient pressures to form blisters, and of course in collecting in the laminations or voids it has to go out of solution. If it were a straight case of the solubility of hydrogen in metal we are compelled to answer the question why did the hydrogen enter the metal and collect in the voids before it took the molecular form rather than to have taken the molecular form at the surface of the metal without making the penetration. I think that in consideration of the subject we must take the attitude, since hydrogen does collect in the voids and in the laminations in the molecular form, that it is necessary to have some pressure on the surface high enough to force the hydrogen through the metal and cause it to collect in the laminations at whatever pressure it does collect. It was on that account that the treatment was presented as possibly a thought in addition to that which has usually been resorted to of explaining the phenomena simply by solubility of hydrogen in the metal itself.

HIGH STRENGTH CAST IRON

By E. J. LOWRY

Abstract

Considerable interest is at present centered about the development of high strength cast iron. The author points out that perhaps the greatest development in the line has been made by European investigators. It is shown that as a rule text book information on cast irons is not representative of the cast iron produced today. It is stated that the addition of alloys is not a means of producing high strength cast iron from inferior irons. Photomicrographs are given of various alloy cast irons, also tables giving physical properties.

THE subject which is attracting great attention in the foundry industry is that which evolves around the methods of production of a high strength cast iron. European investigators have perhaps been more forward in the development of this material than our own research and production men. This is possibly due to the fact that these latter are faced with the problem of mass production, whereas the former are able to give more time to the technical development of processes surrounding the production of higher physical properties in cast iron.

The American foundryman is confronted with the necessity of producing large quantities in melted tonnages. Therefore he cannot consider the affecting of high strength irons without careful thought of the relationship of these new irons in comparison to his present processes. As a matter of fact, it is evident that our present machine tool methods require high speeds and feeds which do not, as yet, lend themselves favorably to what is now called the present "high test" cast irons. Hence the seeming delinquency on the part of American foundrymen to such developments.

When one considers the nomenclature "high test cast irons", it is apparent that the cast iron industry has not taken full recognition of the possibilities existing in the industry. Instead of varying

A paper presented before the Eleventh Annual Convention of the society, Cleveland, September 9 to 13, 1929. The author, E. J. Lowry, member of the society, is a consulting engineer, Detroit. Manuscript received June 3, 1929.

from the empirical standards it is continuing in the same vein. What is necessary is a new method of classification of the varying types of cast iron. This is apparent when one considers the trade name "semi-steel." This is perhaps one of the most glaring incidences in the cast iron field because it will allow a foundryman to make his product with as low as one per cent of steel in the mixture and as high as one hundred per cent steel melted through the cupola. This is no condemnation of the product, but merely shows the latitude within which this type of cast iron may be made.

A second illustration may be made by citing the case of alloyed cast irons. In this instance claims may be made that alloys are used but no full percentage is given. This is merely a detriment in the development of such fields. It therefore becomes necessary, in order to enhance the value of such mixtures, to list, in some way, the type of irons which are offered for use.

The one thought which is most striking would be to classify cast irons under such methods as the S.A.E. designates the various types of steel for definite uses. This would not be an easy matter because cast irons are more complicated in their structure, physical and chemical analysis than steels. If, however, the engineer is to be enlightened as to the possibilities of cast irons, they must be categorically named for him with subsequent listings of what might be expected of cast irons in these classes.

As it is, the engineer is guided solely by text books with an exception here and there of actual experience. The text books to date base their assumptions on strengths obtained under varying circumstances twenty years ago. They further are based on inaccurate determinations in comparison to those made today. It is quite usual that these engineering text books quote the tensile strength of cast iron as a maximum of 14,000 pounds, and more usually at 12,000 pounds. Such physical properties are ridiculous on their face value unless the specimens were cut from 2½-inch sections made from analyses of too soft a chemical composition. As an instance, keeping the section the same and using a different silicon analysis, the strength may be dropped from the range of 25,000 to 13,000 pounds when the silicon is raised from 0.75 to 2.25 per cent. At the time of the writing of engineering text books these features were never given proper recognition, and by the same token if we keep the analysis the same, but vary the section from approximately one half

square inch to $2\frac{1}{2}$ square inches we get comparatively the same drop in strength. It is obviously quite wrong to judge cast iron with 14,000 pounds strength when, by ordinary practice, 28,000 pounds can be readily obtained.

If 28,000 pounds is taken as the average of good practice in the production of ordinary strengths of cast iron, the thought occurs that this strength is taken from a test bar and not from the actual casting. If the casting is at varying section the greater percentage of which is larger than the test bar, the engineering profession may rightly criticize any aspersions that may have been cast on their present methods of accepting the now accredited strength of cast iron. But, if the average casting is analyzed for strength, it will be found that, with the proper manipulation of analyses, the average strength throughout a casting will be far greater than it is now supposed.

It must be pointed out that test bars mean very little under their present acceptance. They are used as comparisons for the physicals obtained by varying the analyses and the irons used in mixtures. They cannot be used to mean the actual strength of a casting. Hence the engineer's doubt as to what strength may be imposed on a cast iron product. There is then an immediate necessity for the development of a test bar which may be easily correlated to the physical properties of a casting. When this is accomplished it will be easier to understand the actions of new processes developed and alloyed irons.

In Europe there are the outstanding processes called the Lanz Perlit which produces low silicon irons poured into heated molds; the Emmel process which is the production of low carbon metal of high silicon analyses; the Piwowarsky and Meyer processes for superheating of cast iron; the Wuest process which requires an oil-fired melting furnace and the Deschene process which subjects the molten metal to a violent agitation. There are many other processes which have been developed in foreign countries, but which have not as yet received practical application. As a matter of fact, the processes listed are not comparative production methods due to the fact that there are limitations for installations in large tonnage foundries.

In America the outstanding developments have been by the late George Elliott who investigated high temperature in relation to the production of high strength castings, and David McLain who has developed the use of steel and cast iron mixtures. The International

Nickel Company, has along with the Electro Metallurgical Corporation, developed the use of nickel and chromium in cast iron mixtures. There are other investigators whose work has been purely for their own commercial application, and for the most part their results have not been published.

The production of high strength cast irons through the use of alloys has long been known, but to produce strengths of 60,000 and 65,000 pounds per square inch has led to the use of special melting processes with the subsequent addition of alloys. Such methods have not generally been accepted by foundrymen. It must be realized that a change of method requires fortitude and courage, whereas a simple method for introduction of alloys could be generally accepted. Any change in the method of melting requires the revising of the usual production processes.

It has been the general thought that alloys may be introduced into inferior irons with the resulting effect that high strength cast irons will be produced. Such is not the case. When anyone is disillusioned on this point it becomes necessary to produce evidence one way or the other. Alloys are not a panacea. They merely act as an aid to the betterment of a condition, and as an example the case of a cylinder head is given. In this situation alloys have been added to correct the pounding down of valve seats but without success. The diagrams (Figs. 1 and 2) with explanations should prove enlightening to one interested in the production of such type castings.

It will be noted that the Brinell hardness is registered over the varying portions, and also that the condition of the metal structures are indicated.

The chemical analyses of two different heads are listed below:

	Head A Per Cent	Head B Per Cent
Total Carbon	3.32	3.21
Graphitic Carbon	2.69	2.78
Combined Carbon	0.63	0.43
Manganese	0.66	0.58
Phosphorus	0.161	0.155
Sulphur	0.065	0.153
Silicon	2.33	2.51
Nickel	0.95	0.93
Chromium	0.01	0.06

The Brinell hardness in these heads was on an average of 179. The main difficulty in this casting was that it was being produced with too high a silicon content for the amount of core annealing

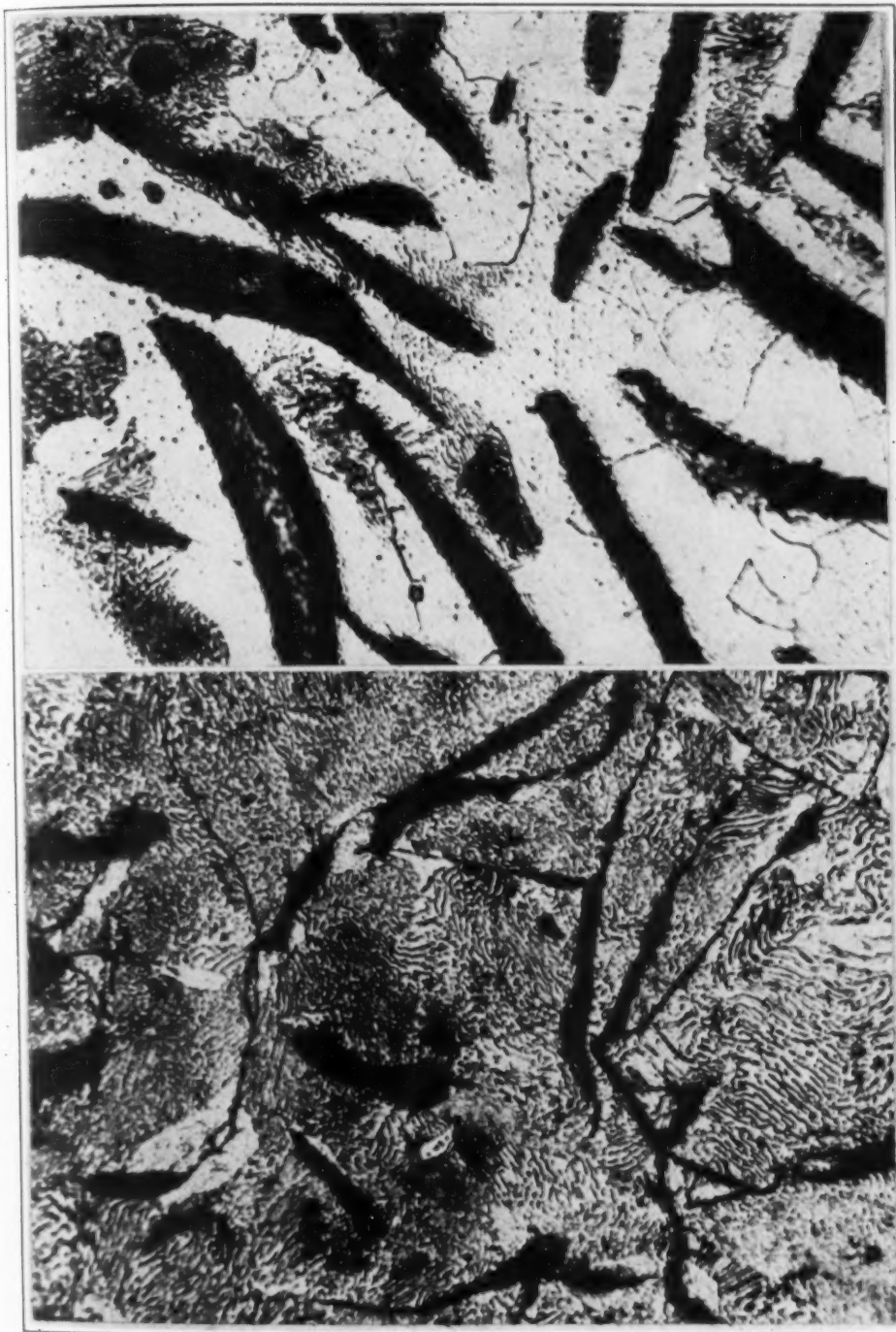


Fig. 3—Photomicrograph of Cylinder-Head Valve Seats Which Hammered Down, Showing Section of Partially Graphitized Metal. $\times 500$.

Fig. 4—Photomicrograph of Cylinder-Head Valve Seats Which Hammered Down, Showing Section of Normal Pearlitic Metal. $\times 500$.



Fig. 5—Photomicrograph of Cylinder-Head Valve Seats Which Hammered Down, Showing Section of Partially Graphitized Metal. $\times 500$.

Fig. 6—Photomicrograph of Cylinder Head Valve Seats Which Hammered Down, Showing Section of Completely Graphitized Metal. $\times 500$.

dryman has adjusted mixtures he can use regular cupola metal and with the addition of one of the known alloys increase his average strength from 28,000 to 45,000 pounds, and even as high as 65,000 pounds. The known alloys are nickel, chromium, molybdenum, vanadium and titanium. These may be used singly or in varying combinations with each other. As an example, the following analyses are given:

	Chromium-Nickel Per Cent	Chromium-Molybdenum Per Cent
Total Carbon	3.34	3.42
Combined Carbon	0.62	0.54
Manganese	0.56	0.59
Silicon	2.49	2.49
Chromium	0.50	0.36
Nickel	1.07	...
Molybdenum .....	...	0.31
Sulphur	0.096	0.075
Phosphorus	0.142	0.135

The above irons were cast on the same day with the same metal mixture, with the only variation being in the ladle alloy addition. The following strengths were obtained:

	Chromium-Nickel	Chromium-Molybdenum
Transverse Strength	3366-2852	3151-3365
Deflection	0.112-0.100	0.110-0.118
Tensile Strength	33,203-33,313	32,686-32,994
Brinell Hardness	217-223	207-217
Depth of chill	5/32-3/16	7/32-1/4
Brinell Hardness (on head of cylinder)	187 to 207	202 to 217
Brinell Hardness (on Cylinder bore)	174 to 179	187 to 192

The following photomicrographs (Figs. 7 to 17) will give a general idea of the structure of cast metal in the cylinder blocks. It will be noted that an apparently equivalent structure exists in both types of alloyed irons. From the standpoint of the chill specimens which are shown in Fig. 18 there is apparently little or no difference in the four specimens in this foundry property.

It will be seen from Fig. 18 on chill tests that No. 4 specimen is a combination of nickel, chromium and molybdenum. This iron gave a relatively better result than either of the two other alloy irons. The strength of this iron ran from 3600 to 4125 pounds transverse strength with deflections of 0.12 to 0.14 inches. The base analysis of the iron was the same as listed under the previous table, the only difference being that about 1.00 per cent nickel was added to the chromium-molybdenum iron. The resulting tensile strengths varied

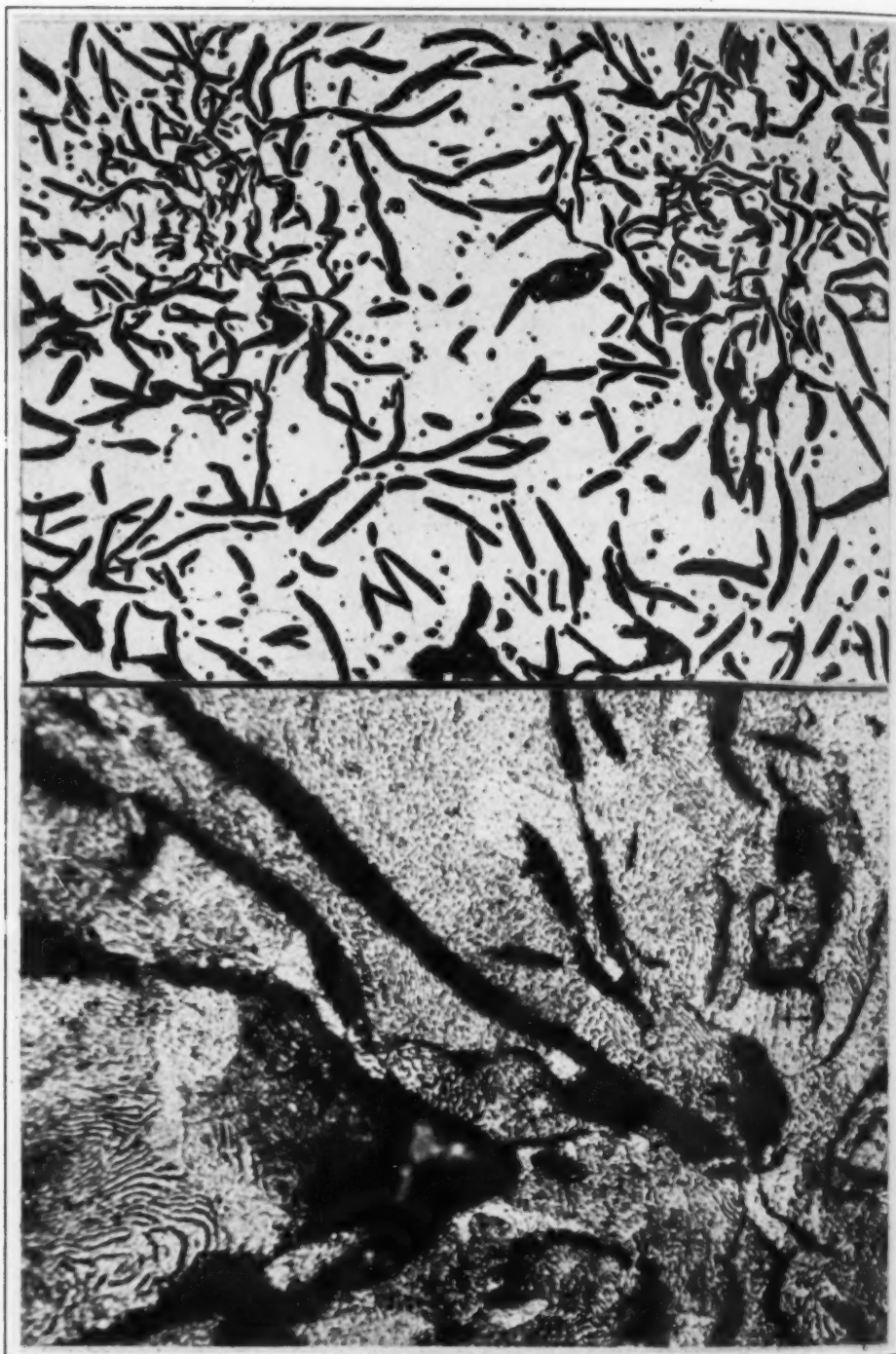


Fig. 7—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Section at the Top of Bore. $\times 100$.

Fig. 8—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Section at the Top of Bore. $\times 500$.

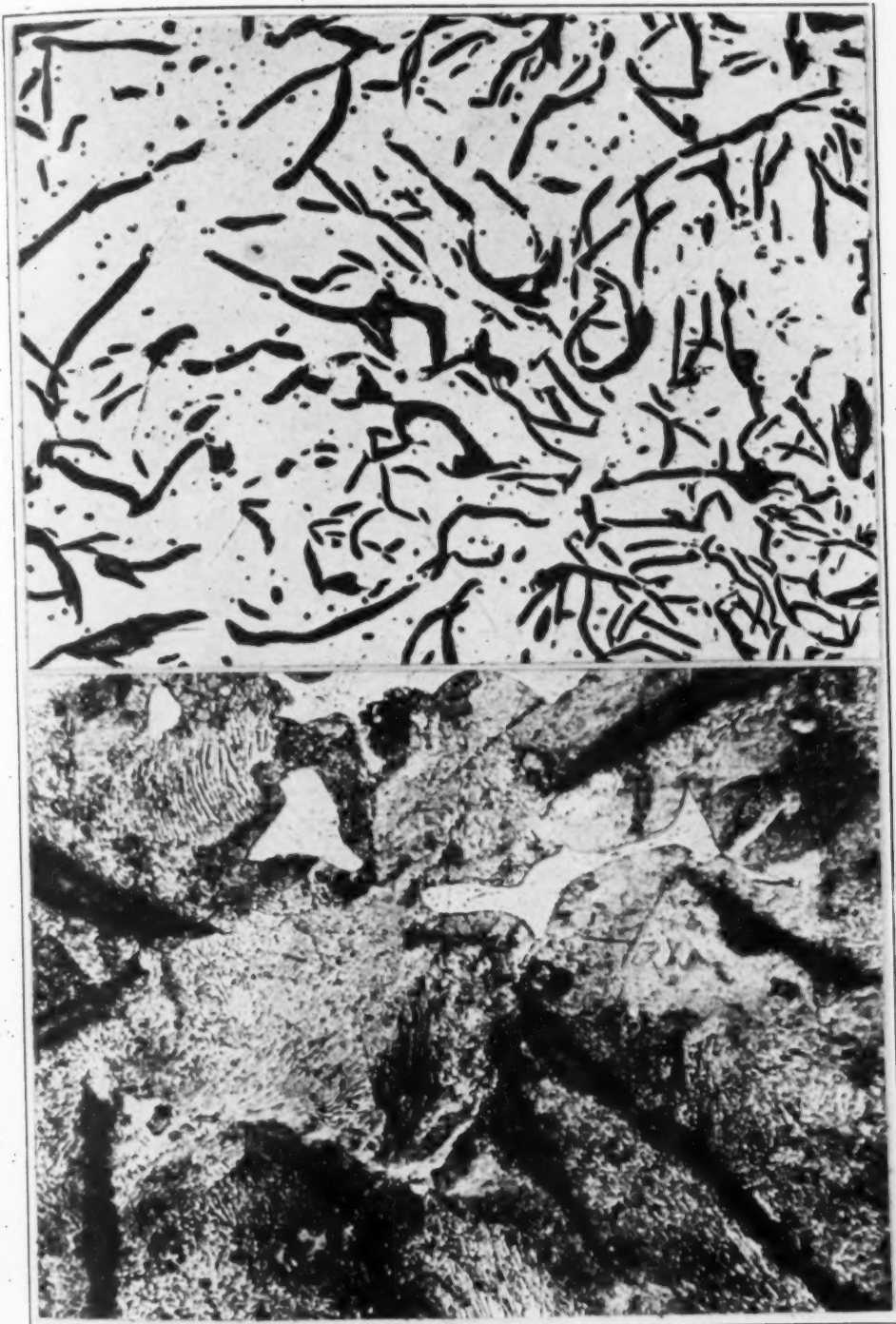


Fig. 9—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Section at the Middle of Bore. $\times 100$.

Fig. 10—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Section at the Middle of Bore. $\times 500$.

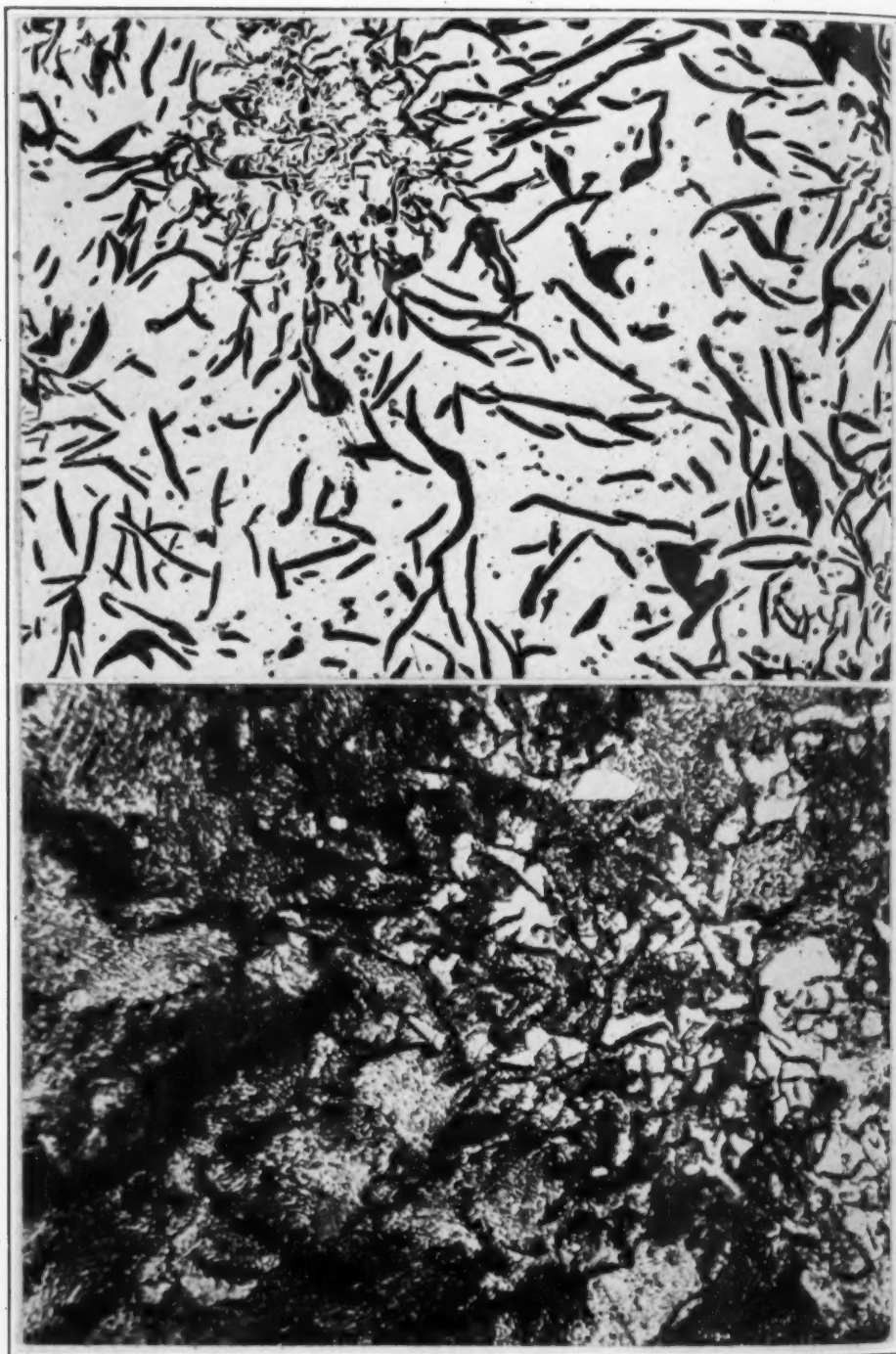
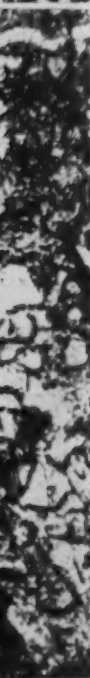


Fig. 11—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Crank Case Wall. $\times 100$.

Fig. 12—Photomicrograph of Chromium-Nickel Iron Cylinder Block Taken From Crank Case Wall. $\times 500$.



From Crank
From Crank



Fig. 13—Photomicrograph of Chromium-Molybdenum Iron Cylinder Block Taken From Section at the Top of Bore. $\times 100$.
Fig. 14—Photomicrograph of Chromium-Molybdenum Iron Cylinder Block Taken From Section at the Top of Bore. $\times 500$.

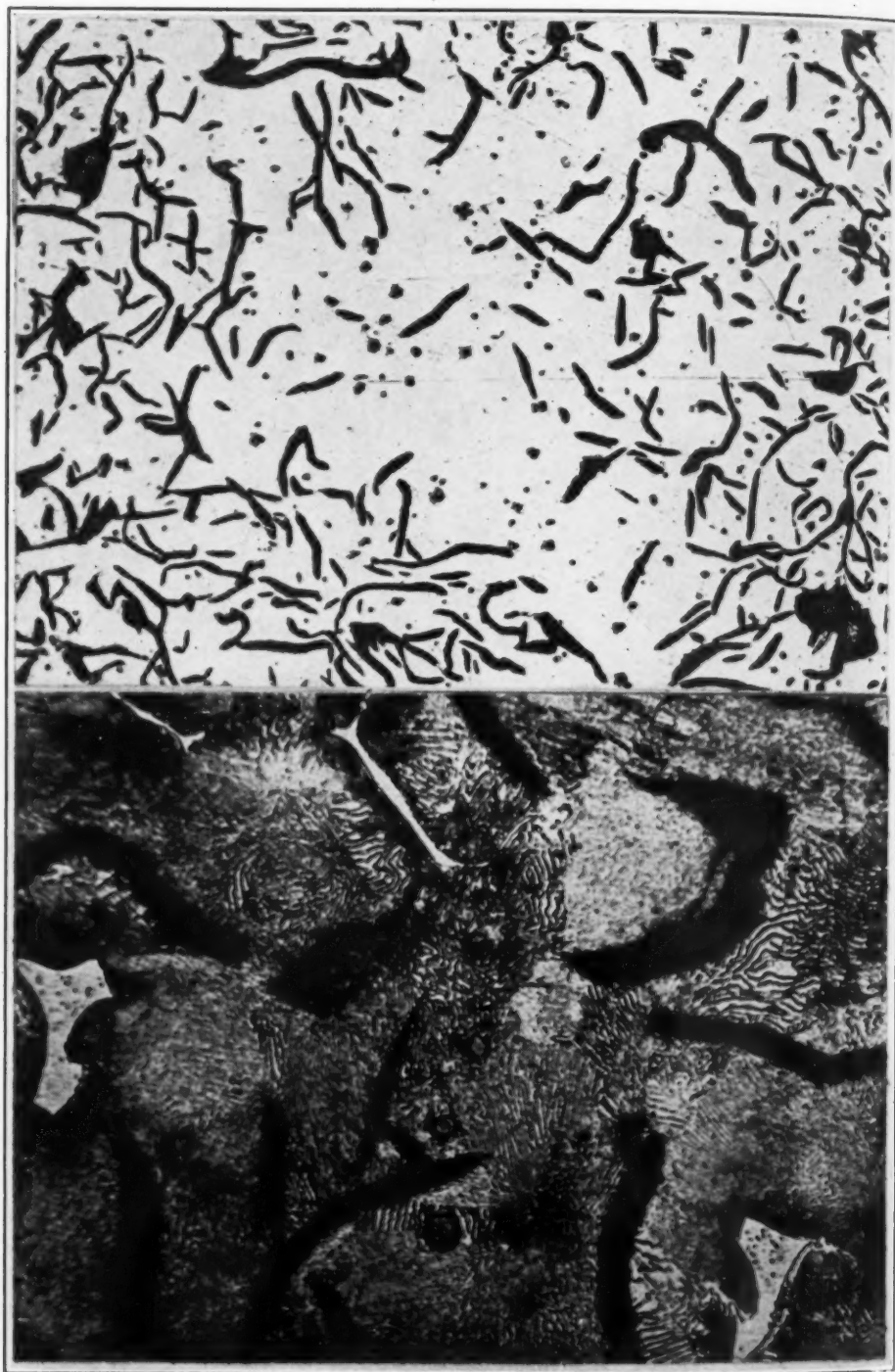


Fig. 15—Photomicrograph of Chromium-Molybdenum Iron Cylinder. Block Taken From Section at the Middle of Bore. $\times 100$.

Fig. 16—Photomicrograph of Chromium-Molybdenum Iron Cylinder Block Taken From Section at the Middle of Bore. $\times 500$.

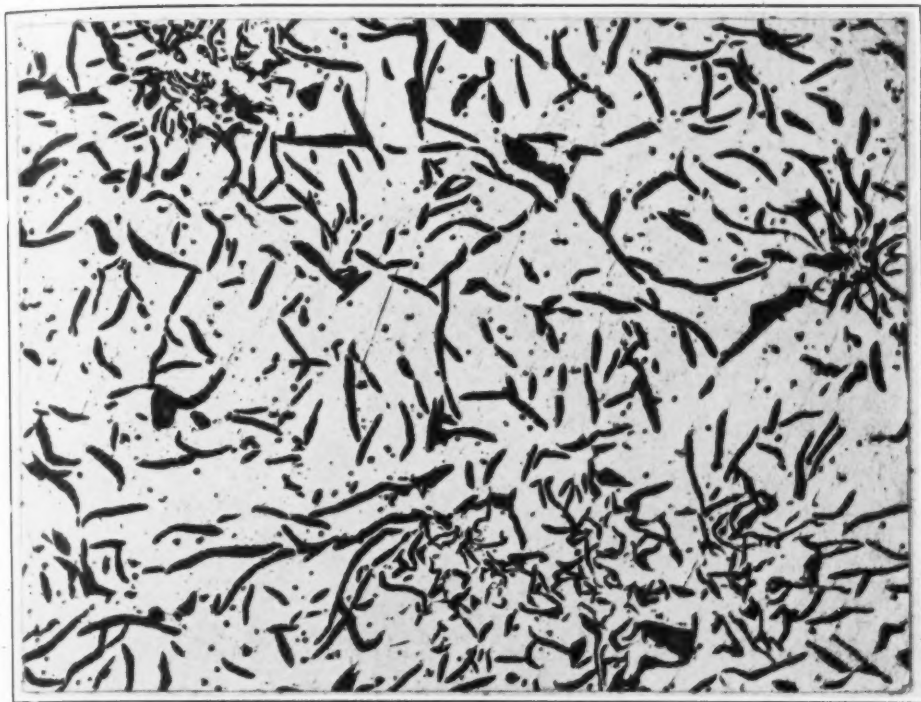


Fig. 17—Photomicrograph of Chromium-Molybdenum Iron Cylinder Block Taken From Crank Case Wall. $\times 100$.

from 38,000 to 43,000 pounds. It was from this test and the results in the application to castings that a further investigation of high strength cast iron was made from regulated cupola irons with subsequent additions of alloys.

Too little attention has been paid to this method of procedure and basically so because of the apparent initial cost. When, however, one considers the use of special melting processes, plus the use of alloys, in comparison to a combination of alloys with regular iron, the resulting costs are apparently the same. It is easier to work with the latter methods than to apply the former in production foundry work.

Vanadium has come into considerable play in the production of automotive forming dies. This alloy is used in the range of about 0.15 per cent with nickel, chromium and molybdenum in small percentages. The effect of this combination is to give increased wearing qualities combined with high strength and excellent machinability. The accompanying photomicrographs (Figs. 19 and 20) give a general idea of the structural-producing effects of this combination.

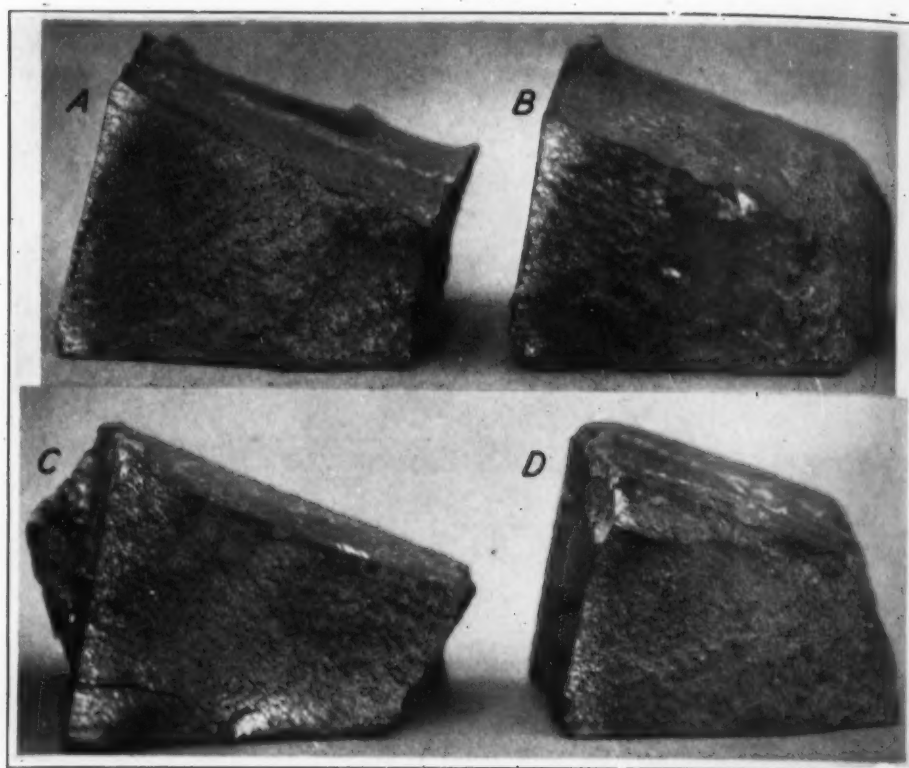


Fig. 18—Photograph Showing Fractures of Chill Tests Made Upon 4 Different Irons. (A) Regular Iron, (B) Nickel-Chromium Iron, (C) Chromium-Molybdenum Iron, (D) Nickel-Chromium-Molybdenum Iron.

In the etched structure magnified to 500-diameters, the pearlitic iron matrix is in evidence. This undoubtedly is the reason for the excellent properties.

There are still further possibilities in the production of high strength irons when the question of annealing is considered. This process will allow a casting to be made harder and stronger but by proper annealing the hardness and strength are little affected and yet the machinability is increased to the point of the lower strength softer cast iron. As an illustration of this process, the following investigation was made:

	Regular Iron Per Cent	High Strength Iron Per Cent
Total Carbon	3.30	3.35
Combined Carbon	0.42	0.64
Manganese	0.63	0.55
Silicon	2.26	1.70
Chromium	0.08	0.63

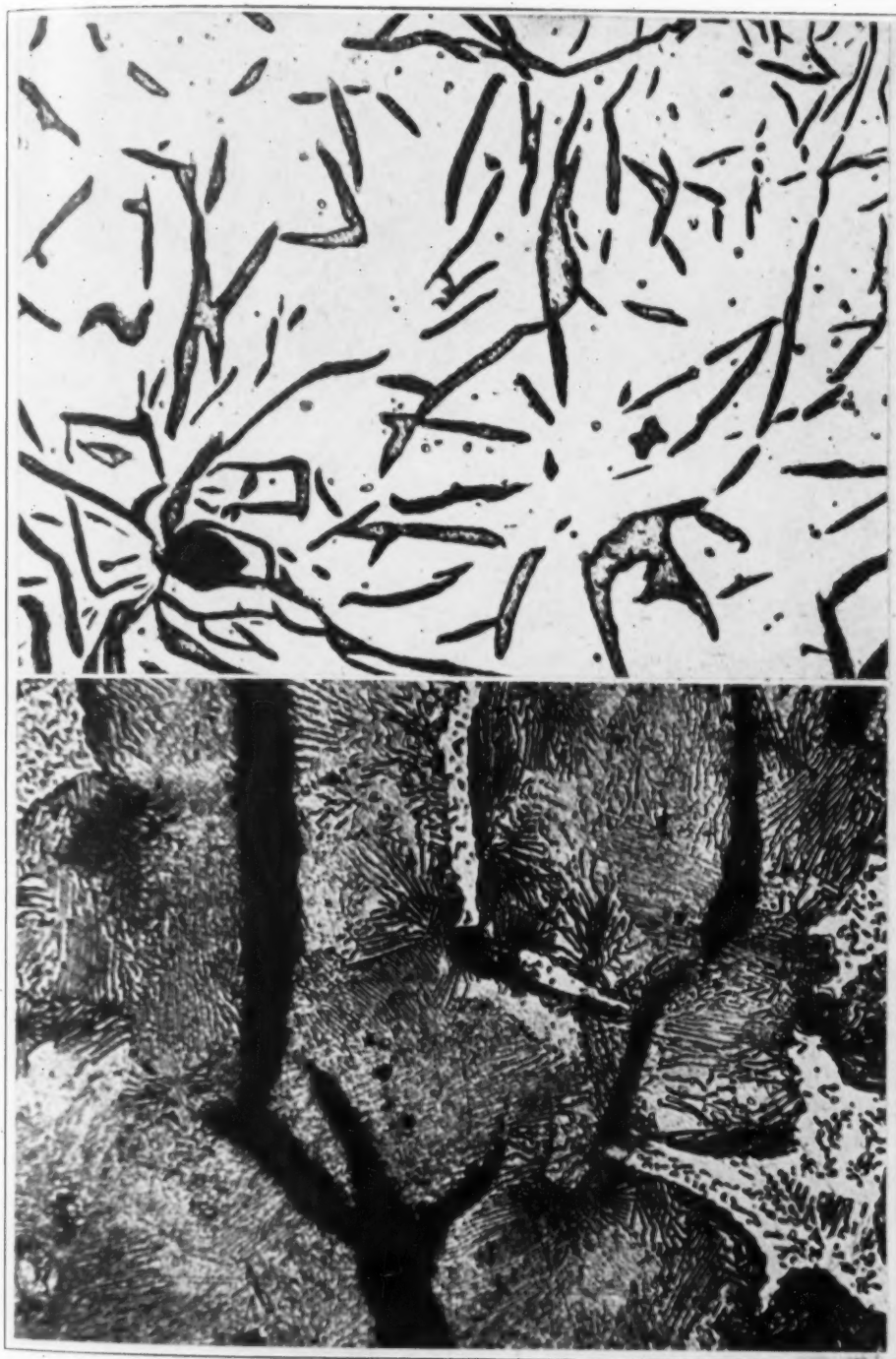


Fig. 19—Photomicrograph of Chromium-Nickel-Molybdenum-Vanadium Iron Automotive Forming Dies. $\times 100$.

Fig. 20—Photomicrograph of Chromium-Nickel-Molybdenum-Vanadium Iron Automotive Forming Dies. $\times 500$.

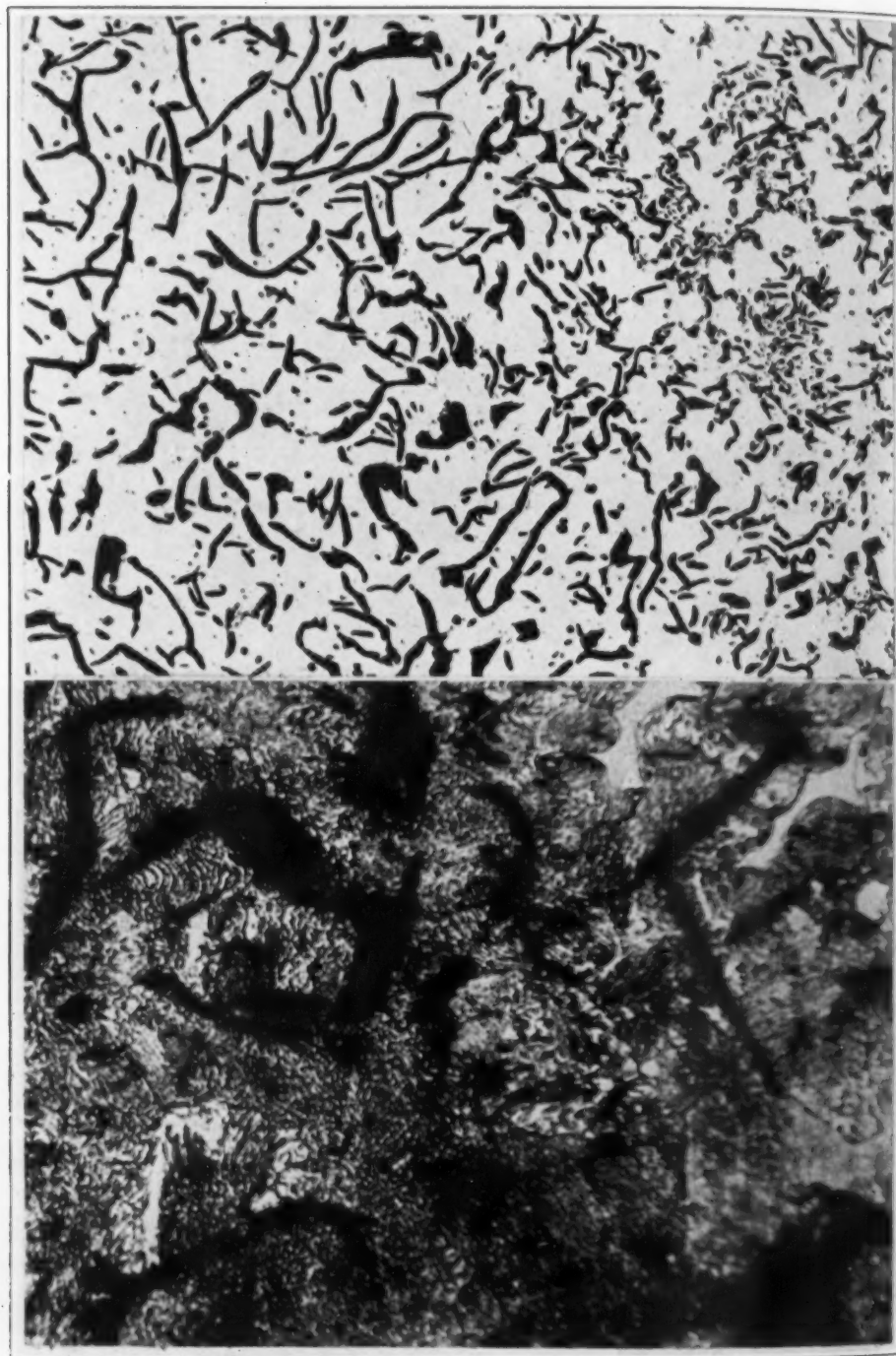


Fig. 21—Photomicrograph of Regular Iron As Cast for Sleeves. $\times 100$.

Fig. 22—Photomicrograph of Regular Iron As Cast for Sleeves. $\times 500$.

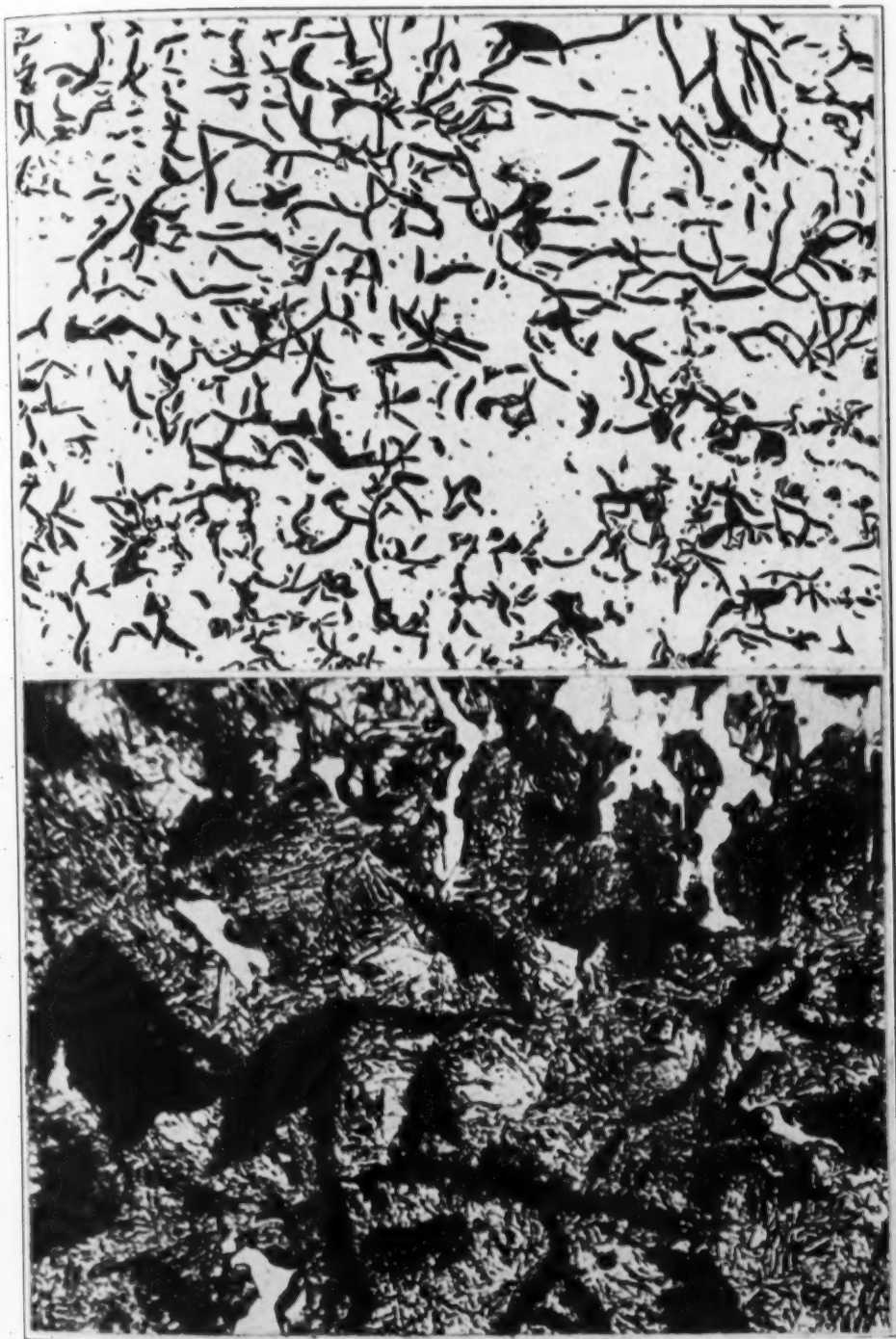


Fig. 23—Photomicrograph of Nickel-Chromium-Molybdenum Iron "As Cast" for Sleeves.
X 100.

Fig. 24—Photomicrograph of Nickel-Chromium-Molybdenum Iron "As Cast" for Sleeves.
X 500.

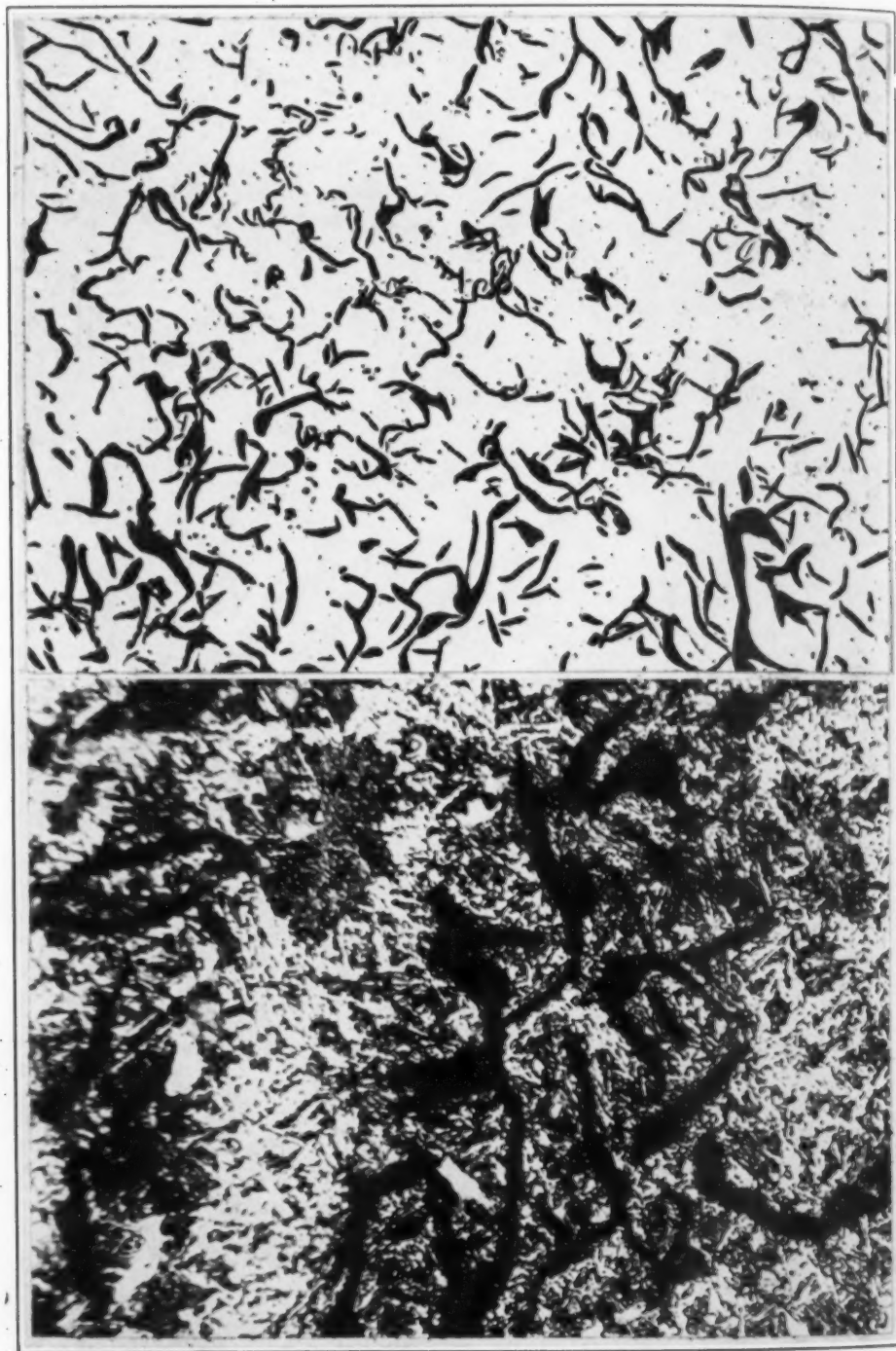


Fig. 25—Photomicrograph of Nickel-Chromium-Molybdenum Iron for Sleeves, Heat Treated. $\times 100$.

Fig. 26—Photomicrograph of Nickel-Chromium-Molybdenum Iron for Sleeves, Heat Treated. $\times 500$.

	Regular Iron Per Cent	High Strength Iron Per Cent
Nickel	0.21	1.46
Molybdenum		0.75
Phosphorus	0.231	0.206
Sulphur	0.104	0.064

The resulting physical properties are listed below:

	Regular Iron as cast	High Strength as cast	High Strength annealed
Transverse Strength (lbs.)	3,099	5,459	
Deflection (inches)	0.105	0.155	
Brinell Hardness	207	321	321
Tensile Strength (lbs. per sq. in.)	25,308	46,039	42,850

The study of the above physical properties and the photomicrographs (Figs. 21 to 26) show that the tensile and transverse strength of the high strength cast iron is about 75 per cent greater than the regular iron. Deflection and hardness are about 50 per cent greater while the structure of the high strength iron is sorbitic with a tendency toward some martensite. The annealing at 950 degrees Fahr. for four hours with subsequent furnace cooling reduces the martensite to sorbite and some of the sorbite to pearlite, thus giving comparable machinability. Undoubtedly if the regular iron was annealed to relieve strains there would be a slight difference in the machinability of these types of irons and in favor of the regular iron.

Further annealing investigations were carried on with these same samples after the first anneal. The cycles of these investigations were annealing 30 minutes at 1100 degrees Fahr. and then 30 minutes at 1250 degrees Fahr., but these showed little or no improvement in the structural composition nor in the hardness and machinability of the samples. Continued experiments with varying analyses and later heat treatments offer great possibilities for the production of high strength cast iron.

In conclusion, high strength cast irons offer possibilities to the gray iron foundryman to not only increase his field of application, but also to regain some of the types of work now being placed in other iron and steel groups. The essential point is that in the present position of development of high strength cast iron this material is still in the experimental stages and further, as it is developed, it will be necessary to classify or grade cast irons according to their merits for the enlightenment of all concerned.

DISCUSSION

Written Discussion: By Frederick G. Sefing, Michigan State College, East Lansing, Michigan.

The author has very modestly shown some of the advantages in the use of high strength cast iron. It is my opinion that the work of the European investigators, with peculiarly constructed cupola forehearth and with electric furnaces, has lead many American foundrymen to think that high strength cast irons are an impossibility without special melting equipment.

Good high strength cast iron can readily be made by the ordinary cupola. However, it is necessary frequently that the melting temperature be raised to as high as 2850 degrees Fahr. This is accomplished by increasing the coke to the ratio of 1 pound of coke to 5 pounds of iron.

Another point in the success of the preparation of high strength cast iron is the proper mixing of the melted metal from the cupola breast. This is especially important when ladle additions are made. Proper mixing is also an important factor in machinability. It is obvious that the cutting properties are rapidly lowered as the metal to be cut varies in composition and consequently in hardness.

The most important factors to be considered in making high strength cast irons are: Correct melting temperatures; Proper mixing of all the elements in the cast iron, that is, the cupola metal with or without ladle additions; Correct mold pouring temperatures. This point is mentioned because this class of irons is tapped a good deal hotter than ordinary iron and it is important to study the proper pouring temperature for each kind of high strength cast iron made.

Written Discussion: By B. F. Shepherd, metallurgist, Ingersoll-Rand Co., Phillipburg, N. J.

Mr. Lowry's discussion of the subject of "High Strength Cast Iron" is very interesting and valuable; particularly from the standpoint of the wide field of experience from which the author has drawn his comments. It may be interesting to give the following figures on some high strength cast iron made by the Ingersoll-Rand Company, which illustrate the differences which may exist between the standard A.S.T.M. coupon and test taken from lugs placed on the castings themselves.

Chemical Analysis					
Heat No.	Total Carbon	Si	Mn	P	S
51990	2.86	1.64	0.78	0.22	0.03
51800-1	2.89	1.56	0.83	0.19	0.065
51800-2	2.72	1.48	0.88	0.182	0.064

Physical Properties						
Heat No.	Bar No.	A.S.T.M. Coupon	Brinell	Cylinder No.	Tensile	Brinell
		Tens. Strength Lbs. per sq. in.			Strength Lbs. sq. in.	
57990	1A	43,013	217	1	29,400	207
	3A	42,914	217	2	35,270	212
				3	32,100	207
				4	32,100	207
				5	38,400	207
				6	33,283	207
Average		42,963	217		33,283	208

Reduction strength of test bars on side of cylinders from individual bars was 22.5 per cent. Cylinders weighed 592 pounds cleaned and coupons attached directly on sides were 1¼ by 1¼ by 6 inches.

Heat No.	Bar No.	A.S.T.M. Coupon Tens. Strength Lbs. per sq. in.	Brinell	Cylinder No.	Tensile Strength Lbs. sq. in.	Brinell
51800-1	1A	43,240	217	1	29,900	196
	1B	43,100	217	2	38,944	192
				3	35,947	196
Average		43,170	217		34,930	195

Reduction in strength of test bars on side of cylinders versus individual bars was 19 per cent.

Heat No.	Bar No.	A.S.T.M. Coupon Tens. Strength Lbs. per sq. in.	Brinell	Cylinder No.	Tensile Strength Lbs. sq. in.	Brinell
51800-2	2C	46,500	223	5	37,600	196
	2G	47,800	223	6	35,843	196
				7	33,265	196
Average		47,150	223		35,569	196

Reduction in strength of test bars on side of cylinders versus individual bars was 24.5 per cent. Directly attached coupons were 1¼ inches by 1¼ inches by 6 inches, but castings weighed 1380 pounds (cleaned).

To determine the effect of annealing half of the test bars, from 2C and 2G, heat 51800-2, were given standard strain-relieving anneal that is, 24 hours at 800 degrees Fahr., cooling in the furnace. The usual practice in taking tensile test bars is to use the lower half of the arbitration bar, taking the tensile bar as close as possible to the fracture in the middle.

On this test the initial bars "as cast" were taken one from the top marked "T" and the other from the bottom marked "B", as close to the middle fracture of each as convenient. Alternate pieces were used for the anneal. The tensile figures "as cast" are repeated for convenience. Apparently the strain-relieving anneal or location of bars has very little effect upon physical properties. All test bars were standard A.S.T.M. A-88-24.

		Tensile Strength Lbs. per sq. in.	Average	Brinell Finished Bar	Flat on bar as cast
As cast					
2 CT (Top)		46,500	47,150	223	228
2 GB (Bottom)		47,800		223	228
Annealed					
2 CB (Bottom)		43,186	45,193	228	228
2 GB (Top)		47,200			

Written Discussion: By H. L. Daasch, Charles City, Iowa.

The fact that we are thinking of "high strength cast iron" is an indication that the foundry industry is on the alert to regain some of its lost prestige. That this is necessary is merely the result of advancement in other engineering materials rather than any retrogression on the part of the cast iron industry.

It must be admitted that nomenclature of foundry products is inexact—that of semi-steel is a glaring example. J. W. Bolton's classification of cast irons as presented before the last A.S.T.M. convention would seem a

beginning, at least, in answer to the author's plea for some such classification.

The author has presented some valuable information on the correlation of cast iron analysis casting section, and processing conditions. The cautions, that alloy irons should be used only after a study of conditions show such to be necessary, are to be commended. Almost without exception alloy additions will increase the cost of metal per unit weight and only when the added expense will show an improvement in product or show a saving in some other stage of processing can this expenditure be justified.

The writer cannot agree with the author that a "test bar which may be easily correlated to physical properties of a casting" should be or can be designed. It would not seem that the problem can be reduced to test bar design.

Two equal casting sections differently placed on the same casting may have widely different cooling rates with resulting widely different properties. Such cooling rates are characteristic for each given casting design and method of production. Considered from this one angle alone, it would seem inadvisable to consider any single test bar as indicative of castings. This does not detract from test bar values as a guide to metal characteristics—but it must be remembered that any test bar regardless of design is the result of a given standardized set of conditions.

The problem would seem then to establish if possible various standard sets of conditions. Individual casting and processing conditions would approximate one of these standardized sets of conditions and a scheme of iron classification as proposed by Mr. Bolton could be used as a basis upon which to apply such standard sets of conditions. A further step, that of heat treating of the various cast irons as classified and as cast under the various conditions would then follow.

Admittedly this is a large order but out of it would evolve a scheme of cast iron information comparable to our present system of steel nomenclature and physical property charts.

Until then it would seem we must follow the system as used by the author in his paper—comparison of various irons by examination of them after being cast into the specified product supplemented by certain physical values obtained from a test bar cast under arbitrary conditions and therefore not comparable to any given casting.

W. J. MERTEN:¹ The trend in gray iron development for its improvement apparently follows the steel casting practice by introducing alloying elements for the improvement of physical properties. Mr. Lowry also points out the general conception that gray iron is a product in which some $3\frac{1}{2}$ to 4 per cent total carbon, of which most is graphite carbon, is necessarily present and that a modification of the properties is only possible, in a practical and economical production scheme, by alloying the iron with nickel, chromium, molybdenum and other metallic elements.

¹Member A. S. S. T., metallurgical engineer, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

Sight is lost entirely of the fact that we have a considerable tonnage of very desirable raw material present as scrap which lends itself nicely to the modification and improvement of gray iron. I have in mind silicon sheet punching scrap, a raw material which has been begging for a market and has been practically piled up for developments. A properly baled charge of this material into the cupola with proper attention to adjustment of coke bed, melting zone and coke additions, gave properties which were equivalent and better than those from the alloyed irons as at present produced in this country. It also permitted a future picture of introducing alloying elements along with this raw material and probably doubling, or at least increasing the properties of the gray iron to a point where it becomes an engineering material of quite some interest.

H. P. KIMBER:² The permanent mold process as developed by the Holley Co., is a new method of casting iron. One of the properties of iron cast in the permanent mold is that it may be hardened. We have been running a number of experiments on various types of castings and have gotten some rather surprising results.

Recently I took some carburetor castings having a cross section anywhere from $\frac{3}{16}$ to $\frac{3}{4}$ inch and carefully measured them after machining. These castings were then heated to 1650 degrees Fahr., and quenched in oil. Apparently they did not grow or distort because the measurements were exactly the same as they were before hardening, so it seems to me that this is another engineering material of some value and we will probably hear more about it in the near future.

Author's Closure

I welcome all the criticism and comments. Some things have been stated in the written discussion that I would like to take exception to; one thing principally is the statement of Mr. Sefing that the temperature of casting should be around 2850 degrees Fahr. in order to produce high strength cast iron and that to obtain that you must have a ratio of 1 pound of coke to 5 pounds of iron. I have been in numerous foundries throughout the country and find that 2750 to 2800 degrees Fahr. is the average pouring temperature of normal cast iron.

In order to get good high strength cast iron I have found that you have got to take it up to pretty high temperature in the neighborhood of 3000 degrees Fahr. If you have an electric furnace in the cupola operation, 2800 to 2900 degrees Fahr. would be attained if you were using 100 per cent steel with a coke ratio of around 7 to 1. It has been a misconception that the bed must be high—that you need a 60-inch bed. Just recently we have been operating and producing high test cast iron with beds around 40 inches. I do not think that anyone could dogmatically give an outline that could be followed by every foundry due to the fact that the foundries are not standardized in their equipment.

Mr. Sefing further points out that the mold pouring temperature has an influence upon the production of high strength cast iron. I think that there is

²Member A. S. S. T., metallurgist, Holley Permanent Mold Machine, Inc., Detroit.

some difference of opinion on this point because some people will pour the iron hot depending upon the sand. Some people will take the same iron and hold it in the ladle because of difference of type of castings that they are pouring.

Mr. Shepherd has pointed out that test bars on the castings and test bars of the A.S.T.M. do not give the same results. He says that the test bar cast singly will give a strength of about 43,000 pounds and the test coupon will give 33,000 pounds. That is with your practice of casting test lugs on the casting. They are very much in favor of it, but if you vary the distance of that test coupon from the gate or the entrance of the metal into the mold cavity you will immediately change the strength of the iron or the strength of the lug. Therefore, the test lug has no more real value than the single cast test bar.

Mr. Daasch pointed out that you could not get test bars which would be easily correlated to a casting. I can readily admit that. I think everyone would agree, but there is, or will be, discovered some time at least one, or a series, of test bars which may properly represent the strength of the casting.

There is one thing I want to bring out, and that is after going over these practices and trying them, and then coming back here and witnessing the progress we have made, I really feel that the cast iron which we are making, not with a pet process or a patented process, but just by the use of alloys is just as great an improvement, if not a more standardized and practical improvement than these patented processes that are being worked in Europe.

A HEURISTIC THEORY OF THE STRUCTURE OF STEEL

BY LEON CAMMEN

Abstract

According to the new theory, steel consists not of an aggregation of crystals with an amorphous cement in between, but of a matrix of extremely fine crystalline matter (so fine that even the most powerful microscope of today does not disclose its structure) in which are embedded the now visible crystals of the same presumable composition as the matrix material. This theory is said to explain why at room temperature steel breaks through the crystals and not through the cement. It also apparently explains the mechanism of gradual growth or refinement of visible crystals, as well as the appearance or disappearance of the intercrystalline material. While there is no positive evidence to support the contention that what is generally referred to as amorphous cement is really a finely crystalline material, circumstantial evidence is adduced in proof of the new view.

THIS is the kind of theory which seems to fit the facts and yet, like Berkeley's philosophy, can neither be proved nor disproved, at least with the laboratory instrumentalities which we are blessed with today.

Basically, the modern view is that steel consists of crystals with the spaces between them filled with an amorphous cement. The microscope shows us the crystals, so that there is little doubt about that part of it. We know that there is something in between the crystals, a fact which, in the language of the English public school song, "no one can deny." The only question is, what is this something.

Why does this intercrystalline cement have to be amorphous, and would not we get along further by assuming that it is also crystalline, but with a grain so fine that our rather weak microscopes cannot see it? There is a good deal of what might be called circumstantial evidence that this may be so.

In the first place, there are other materials which have been as-

The author, Leon Cammen, is associate editor, *Mechanical Engineering*, and consulting metallurgist New York City. Manuscript received December 6, 1929.

sumed to be amorphous, and which, we are learning now, are merely so finely crystalline that we did not see the crystals. Such seems to be the case, e. g., with rubber, and, what is more, the wonderful physical properties of rubber are most intimately interwoven with this fine crystallization, as evidenced by the fact that natural rubber has the crystallization and the properties while synthetic rubber, though of the same chemical structure, lacks both the first and the second.

Inherently, there is nothing definite to make such a supposition impossible in the case of the intercrystalline cement. Just because we do not see the crystals, does not prove that they are not there. For a very long time we did not see the crystals in rubber either. The fact that comparatively large crystals of the visible range cohabit with the fine crystals of the cement is interesting and with our present knowledge of crystallography inexplicable, but if we rejected in crystallography all that we cannot explain, we might just as well burn all of our books on this intriguing subject.

Even in a heuristic theory, however, mere negative evidence is insufficient, and at least a modicum of positive evidence should be adduced. The most powerful argument in favor of the crystalline nature of "amorphous" cement is constituted by the physical properties of steel, viz., the fact that at room temperature ordinary steel breaks through the grains; and at elevated temperature through the intercrystalline cement. This of course indicates that at room temperature, the cement is stronger than the crystalline part of the metal, and the surprising part of it is that this applies not to compression, but to tension and alternating stresses.

That amorphous masses may be highly resistant to compression, is understandable. Amorphous masses, as we know them, are apparently composed of elements of matter (atoms or molecules) haphazardly arranged, and it has been our experience, easily supported by the application of mathematical methods, that whenever matter is arranged otherwise than in accordance with a regularly repeating lattice, the utilization of space occupied by the matter is poor. In other words, there are considerable voids between the particles of matter. When compression is applied, there is a forced rearrangement of the particles bringing them closer together and hence increasing their ability to resist the strain to which they are being subjected. On the other hand, when tension stresses are applied,

the tendency is to increase the voids which are already great, with the result that some of them rapidly become greater than the maximum which can be maintained without causing a permanent rupture, and this results in a failure of the material.

When steel fails by rupture across the crystals, this indicates that, first, the cement is stronger than the crystal, and second, that the bond between the cement and the crystal is also stronger than the later, but this bond may be considered as a layer of the amorphous material say one molecule thick somewhere very near the crystal. The situation here is somewhat similar to what apparently happens in the case of a metal surface lubricated by an oil (Langmuir, Trillat, etc.). We have there a body of metal, such as the cylinder of an air compressor. Next to it we have a layer, one molecule thick, of a compound of the metal and oil or solution of the former in the latter; next to it we have a body of oil which may be considered as consisting of superimposed leaves (like a leaf spring) or layers of oil likewise one molecule thick. In order that a film of oil could be maintained between the two metal surfaces, it is necessary that the strains imposed on the oil be less than the tensile strength of each layer as otherwise rupture will occur.

This rupture may occur in several ways. Suppose that we lay two flat metal plates on top of each other, and spread some oil in between them. We then attach one plate to the foundation and gradually raise the other. Ultimately, with good lubricating oil, the plates will tear apart, but both will remain smeared with oil. Here the bond between the metal and oil is stronger than the oil itself. If instead of oil we take certain types of glue and let it dry fully before we tear the plates apart, the plates will separate but with very little glue sticking to them (or rather one of them). Here the strength of the glue is greater than that of the bond between the metal and the glue. Finally with good welding we may obtain such a joint that it will break not at the weld but through virgin metal. If we believe our friends in the welding field, this is due to the fact that the metal in the weld and the joint between the weld and the original metal is stronger than the latter.

And such is the case when ordinary steel is broken in tension. As the break occurs through the grain and not at its boundary, it indicates that the grain is weaker than either the bond between it and the cement or the cement itself. Since, however, all indications

are that the cement and the grain part of the steel are the same in chemical composition, and go through the same process of heat treatment, we have the rather unusual picture of an amorphous material being stronger in tension than a granular material of the same chemical composition and the same origin, something that cannot be accepted without very good proof.

There is another difficulty with the amorphous theory, and this is that it does not explain the growth of crystals. We know that this can take place while the metal is in what we call the solid state. We know from other evidence that two or more crystals may coalesce under certain conditions of electrical potentials, or, expressed more crudely, temperature and pressure, but where do we know of cases of a crystal being capable of transforming adjacent amorphous material *in the solid state* and using it for its own crystalline growth? If the intercrystalline cement is amorphous, we have to adopt one of the following two processes in order to explain crystal growth in the solid state. The first is that the amorphous matter is used by the crystal for its own growth, to which we have referred above. The other is that the growth of crystals in steel occurs by coalescence of existing crystals, the cement remaining substantially neutral. There is good reason to believe, however, that the growth does not take place that way. In the first place, it is apparently a fairly continuous process, the crystals growing gradually. If the growth took place through coalescence of existing crystals which, we know, are fairly large even in the so-called finely crystalline steel, we would inevitably observe sudden jumps in the size of the crystals, and we do not.

Furthermore, if growth of crystals took place through coalescence of existing crystals, what becomes of the cement supposedly located between these crystals? It would have to be shifted out of the way somewhere, and such shifting would consume energy and hence heat. The result would have been that as the crystals are growing, the temperature of the metal would be slipping. We have no evidence of that.

On the other hand, if we assume that the intercrystalline cement is not amorphous but consists of extremely fine crystals, all of these difficulties disappear at once. As the electrical conditions in the metal change as a result of altered temperature, the crystals pass from the state of single blessedness in which they were in the cement, to become part of an aggregation of similar crystals in what we call

"crystals" today, and the growth of the big crystals proceeds in accordance with the usual processes governing this phenomenon. There is no question then of displacement of the cement to make room for the bigger crystals, this room being created by the migration of the fine crystals from the cement into the visible crystals, and vice versa.

The amorphous hypothesis of intercrystalline cement becomes still more difficult to use when it comes to the explanation of what happens when a coarsely crystallized material is changed into one finely crystallized, as e. g., happens in the case of forging. There is no evidence to show that we actually shatter the crystals, and, what is more, when we do break up a crystal by mechanical means, the cleavage takes place along certain mathematically predetermined planes, with the result that the original single crystal breaks up into several smaller crystals, and not into one smaller crystal and a mess of amorphous material. If such is the behavior of ordinary crystals, why should steel crystals behave otherwise?

What is more, here again we are encountering a special difficulty. If steel consists of crystals and an amorphous intercrystalline material, and the size of the crystals is reduced, the loss of the crystals must obviously pass into the amorphous material. We know, however, that the latter occupies more space than the former which means that when this happens, several things will be observed. In the first place, there will have to be an expenditure of energy in order to push aside the adjacent material to make room for the new amorphous mass, with consequent loss of temperature. There is no evidence of that.

In the next place, as the crystals become smaller, the percentage of cement in the mass becomes greater. This is not quite obvious at first glance, but will become plain if we remember that the decrease in the size of the crystals does not occur in big jumps, but, like the increase, takes place gradually, and hence happens not through splitting of the bigger crystals, but through loss of crystalline matter to the cement. The only other possible supposition, namely, that when the crystals become smaller, some of them are created through transformation of the amorphous mass into crystalline, could be accepted only if it were proved that such a process can take place in solid metal or in the solid state generally, which seems to be contrary to what we do know of crystal formation today.

If, however, the percentage of the amorphous mass in steel be-

comes greater, its ability to resist tensile and shock stresses ought to decrease, because of the usually accepted physical characteristics of amorphous masses is their inability to resist this kind of stresses. And yet it is a well known fact that finely crystalline steel is stronger in these very respects than coarsely crystalline metal. If, on the other hand, we assume that the cement is not amorphous, but crystalline in a supreme degree, this relation of size of crystal to strength becomes natural and consonant with what we know of crystalline materials. As the crystals (visible) in steel become smaller, not only is the percentage of the very fine crystals in the cement increased, but the cement matrix is less interrupted by the crystal islands, and becomes therefore capable of more resistance to various stresses.

What is then the true structure of steel according to this theory? Steel consists of a matrix of extremely finely crystalline matter in which are embedded crystals of (presumably) the same composition, but very much greater dimension. Under certain conditions of temperature, migration from the finely to the coarsely crystalline regions and vice versa takes place, resulting in the growth or decrease in size of the visible crystals, but apparently affecting only the number, and not character of the invisible ones. Just why steel crystallizes along two different methods, we do not know. We do know, however, that before complete freezing steel passes through a state which the mill man describes as mushy, and the physicist designates as the state where the metal is partly liquid and partly solid. The metal then passes through the delta stage, and completely changes its atomic structure in the course of transformation to the gamma stage. It would appear therefore that in its metamorphosis from the liquid to the gamma iron, the metal undergoes several processes accompanied by—probably—powerful changes in pressure which may have something to do with the size of the crystals formed in each such period. We know, however, so little about what happens in steel between that part of the area of the equilibrium diagram which deals with completely liquid metal, and the gamma iron stage, that there is only one thing certain, and that is, that no matter what guess we may make, it will not tell the full and true story.

From the point of view of physical properties of steel, there appears to be a certain analogy between steel and cast iron if we compare the fine crystal matrix (i. e. the so-called cement) with the iron matrix of cast iron, and visible crystals with the embedded car-

bon: In cast iron, the carbon is the element of physical weakness, and so are the visible crystals in steel. As the size of the particles of carbon in cast iron decreases, the strength of the metal increases and so does malleability. Coarsely crystalline steel (which, in this case, means steel with coarse visible crystals) is also more brittle than steel with fine visible crystals.

The above theory is merely heuristic. It appears to explain certain facts, but so far there is no positive evidence to support the view that the so-called intercrystalline cement is not amorphous but highly crystalline, and that its function is that of a matrix, and not cement at all. That there is no positive evidence of the assumption that the intercrystalline cement is itself crystalline may be at least in part accounted for by the fact that no one has been looking for it.

MELTING PRACTICE FOR THREE TYPES OF BASIC ELECTRIC STEEL

BY H. P. RASSBACH

Abstract

The melting practice for three types of electric furnace steel is described. Three specific heats are discussed. The heats selected are carbon tool steel, chromium-vanadium steel and high speed steel.

The selection of proper scrap for each charge is discussed. It is shown how savings may be effected by selection of suitable scrap.

The slag conditions at various stages of the heat are described. Slag and metal analyses are given.

The importance of deoxidizing the slag to a high degree is emphasized. It is shown that slags high in oxides may be almost completely deoxidized.

General furnace practice is described from a practical viewpoint.

INTRODUCTORY REMARKS

THE purpose of this paper is to describe from a practical standpoint the practice used in melting three outstanding types of steel now made in the basic electric furnace. These three types are as follows:

1. Plain carbon steel—low phosphorus and sulphur content specified.
2. Simple alloy steel—chromium-vanadium, chromium-nickel, chromium-molybdenum, etc.
3. Complex alloy steel—high speed steel or any steel containing a high percentage of alloys.

The melting record of one heat of each type is given and the melting practice is described. The scrap charges and necessary slag condition at various stages of the heats are discussed. The three heats selected are, plain carbon tool steel, chromium-vanadium steel and high speed steel. These steels are made in large quantities in

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the basic electric furnace and are therefore of general interest. No mention is made of special heat resisting and corrosion resisting steels because each type involves problems which are not of general application in electric furnace melting.

The furnace used is a 7½-ton capacity Heroult. Three phase current is available on three voltage taps, 175, 120 and 90 respectively. The maximum power used on the 175 volt tap is 2500 KVA. The three 17-inch diameter carbon electrodes are automatically controlled. The bottom is made of magnite set on magnesite.

CLASS I

CARBON TOOL STEEL

Table I gives the melting history of a heat of plain carbon tool steel. This type of heat was selected because it illustrates clearly the ease with which oxidizing and reducing conditions may be established to bring about the desired results. The practice employed in making this heat can be applied in making any heat in which it is necessary to reduce both the phosphorus and sulphur to a low figure. The discussion which follows is general for the type and not confined merely to the heat shown in Table I.

The Charge

The carbon content of the charge should be fairly close to the desired carbon. Coal can be added to the charge to bring the estimated carbon to the proper point but it is undesirable to use large quantities of coal in this manner. The presence of a large amount of free carbon will retard dephosphorization. It is also difficult to obtain consistent results in the amount of carbon in the bath when large quantities of coal are used. In some cases a large portion of the coal is lost before the bath is melted, resulting in a low carbon. The carbon of the bath, when melted, should be within 20 points of the specification.

It is not desirable to use scrap having a high phosphorus content, that is over 0.05 per cent. There is no question that the phosphorus can be removed, it is merely a matter of economy. Electric energy is rather expensive to use for this purpose. The phosphorus content of the scrap should be sufficiently low to allow the necessary dephosphorization to be completed by the time the heat is melted.

Table I
Carbon Tool Heat
E 2793

Summary		Per Cent				
	C	Mn	P	S	Si	
Estimated in Charge.....	1.20	0.40	0.035	0.039	0.18	
Determined in test-before additions.....	1.10	0.28	0.018	0.038	0.03	
Taken up to	1.12	0.28	.....	.....	0.20	
Specified	1.15	0.25	<0.025	<0.025	0.20	
Ladle Test	1.12	0.28	0.019	0.015	0.20	
Time	Operation					
11:55-12:20	Charging 18,000 pounds of spring scrap and 100 pounds of coal.					
12:20	Power on—2500 K. W.—Add 200 pounds of lime.					
1:40	Change power to 1700 K. W.—Scrap on banks pushed in.					
1:45	Add 150 pounds of iron ore and 100 pounds of lime.					
2:05	Melted—Add 100 pounds of lime. Change power to 900 K. W.					
2:15	Test—carbon 0.98, phosphorus 0.018.					
2:30-2:40	Removing the slag.					
	Partial analysis of slag CaO 42.00% SiO ₂ 18.65% P ₂ O ₅ 4.44% FeO 13.32%					
2:40	Add 36 pounds of 50% FeSi and 55 pounds of coal.					
2:40-2:50	Working in the coal.					
2:50	Add 200 pounds of lime, 50 pounds of spar and 25 pounds of sand.					
3:05	Test—carbon 1.10, Mn 0.28 P 0.018 S 0.038 Si 0.03.					
	Partial analysis of slag CaO 62.60% SiO ₂ 16.15% P ₂ O ₅ 0.094%					
3:20	Add 25 pounds of coke and 50 pounds of lime.					
3:35	Add 150 pounds of low phosphorus pig iron.					
3:40	Add 15 pounds of coke and 50 pounds of lime.					
3:55	Add 72 pounds of 50% FeSi and 50 pounds of lime.					
	Test before Si shows Si 0.02%					
4:10	Tap.					
	Partial analysis of tapping slag.					
	CaO 62.00% SiO ₂ 21.60% P ₂ O ₅ 0.058% FeO 0.45%					

It might be well at this point to mention the desirable physical characteristics of an electric furnace charge. The Heroult furnace melts the charge for the most part starting at the bottom. The electrodes cut their way through the scrap, continuing down until a pool of metal is formed on the bottom. They slowly rise as the pool becomes deeper until all the scrap in the center of the furnace is melted. It is well to have the charge covered over with turnings or small scrap of some kind to keep the heat in the charge. This is of special importance when large pieces of scrap are used in the charge. It has been found that large pieces of scrap, namely, 15 or 20 inches in diameter, do not increase the melting time if they are properly covered over with small scrap. The use of too much very small close

packing scrap should be avoided. Serious melting delays may result when too large a quantity of such scrap is used as the electrodes will not cut through the charge because the contact is too good. They will remain on top and melt the charge from the top down, which will necessitate reducing the power to avoid overheating the furnace. As much as two hours may be lost in melting such a charge.

Melting Practice

The conditions which determine the changes which should be made to the power will vary greatly in different heats. Therefore, this subject cannot be covered in detail. A generality which might be made is that the high power should be kept on as long as possible without injuring the furnace. This will result in having the pool sufficiently hot to melt the scrap which is pushed in from the banks at the time the power is reduced. It is well to leave some scrap on the banks until the time has come to reduce the power. It will serve to protect the walls from the arc.

When the bath is practically melted a small amount of iron ore should be added with a generous amount of lime. See Table I. The addition of sufficient lime is very important. Unless there is a large excess of available CaO to combine with the P_2O_5 , the phosphorus may easily be reduced back into the bath. Large ore additions are unnecessary. They should be avoided. The bath may become so oxidized that the reducing slag may not succeed in cleaning it as well as it should. The oxidation of phosphorus is an exothermic reaction and is therefore more easily accomplished at low temperatures. Hence it is well to add the ore before the bath is very hot. The removal of phosphorus to the desired extent may be thus effected by the time the bath is thoroughly melted.

As soon as the bath is entirely melted and is sufficiently hot a test is sent to the laboratory for carbon and phosphorus. It is necessary to know the amount of carbon when the oxidizing slag is removed in order to add the coal necessary to correct the carbon. It usually requires about ten minutes to remove the slag. Thus if the operation of removing the slag is begun 15 minutes after the test is sent to the laboratory the results of the test will be obtained when the slag is removed. Time may be saved by following this practice.

When the slag has been taken off clean, 0.10 per cent of 50 per cent FeSi should be added. This will hasten the process of cleaning

up of the bath. Anthracite coal in sufficient quantity to correct the carbon content of the bath may also be added at this time. The coal may be worked into the bath either by means of bars or wooden poles. The FeSi should never be added until all of the slag has been removed, as the silicon will reduce into the bath the phosphorus contained in the slag.

Several factors influence the accuracy which may be obtained by the method of raising the carbon described above. The oxidizing slag must be cleaned off well. If the men have been careless in leaving slag in the furnace a considerable portion of the coal may be retained in it. The melter should avoid having too strong an oxidizing condition when melted. A bath having a strong boil is difficult to slag off cleanly. Furthermore, the carbon content of the bath will be dropping too rapidly while the test is in the laboratory. These two factors together may result in the carbon in the final test being much lower than is desired. It is totally unnecessary to have such a strong oxidizing condition to remove phosphorus.

It is good practice not to add the coal or silicon after the slag is removed until the phosphorus test has been reported. In the event that the phosphorus is not sufficiently low, lime and some fine iron ore may be added which will speedily eliminate more phosphorus. However, if the coal and silicon were added before it were known that the phosphorus was high much time will be lost in oxidizing the phosphorus as the reducing action of the silicon and coal must be overcome first.

It is hardly necessary to mention the evil effects that any large quantity of oxidizing slag, carelessly left in the furnace, may have on the heat. Sufficient phosphorus may be reduced from this slag into the metal to result in the heat finishing too high in phosphorus for the specification. The presence of this slag will make it very difficult to make a good reducing slag without loss of time. Thus the resulting product may be a steel high in phosphorus and containing an excessive amount of inclusions or dirt.

The advantage of having the heat melt fairly close in carbon to that desired is that only a relatively small amount of coal or pig iron need be used to correct the carbon. There is an element of chance involved in this procedure regardless of the care taken. There is much less risk involved in attempting to raise the carbon content 20 points than in attempting to raise it 50 or more points. When the final carbon is too low only two courses are available, a large amount

of pig iron necessary may be added or the slag may be removed a second time and more coal added. Large additions of pig iron have a harmful effect on the metal, although it is difficult to specifically indicate what harmful condition such additions bring about. The fact that they are harmful has been shown by experience in regard to electric furnace steel as it has been in open-hearth steel.

When the coal appears to be all worked into the bath the reducing or finishing slag is made. Spar and sand are added in sufficient quantities to make the slag of proper consistency. Care should be exercised not to get the slag too thin. The slag, when properly made, will appear foamy under the electrodes. Normally, a slag deoxidizer is not necessary in making the finishing slag when the carbon content of the bath has been raised by means of coal. There is probably enough coal left undissolved to deoxidize the slag. In the case of the heat shown in Table I the slag crumbled to a white powder 15 minutes after it was made. The test for carbon and manganese was then sent to the laboratory. During the next 15 minutes the slag became slightly dark, indicating the presence of oxides. Evidently the bath was not entirely deoxidized. An addition of carbon made to the slag quickly changed the slag to its original white color. Frequent slag samples taken during the remainder of the heat were all white. All future reference made to a "white slag" will indicate a slag which will disintegrate into a white powder upon cooling and may give off a slight odor of acetylene when moistened.

Upon report of the carbon and manganese test, any additions necessary are made. When they have been held a sufficient time the silicon is added and held until thoroughly diffused. In regard to holding the finals, it is well to make a set rule governing the minimum time that should be taken. This may be conveniently expressed in terms of so many minutes for 100 pounds. The practice of tapping as soon as the finals are melted seems to be unquestionably bad. It is specially important to hold the silicon for a considerable time. If the slag is deoxidized there is no danger of having a large loss in this element. Therefore every opportunity should be given the products of deoxidation resulting from the silicon addition to rise out of the bath. It is true that there are very few oxides in the bath of a properly handled electric heat. Regardless of that the bath should be given every opportunity to clear itself after the silicon addition.

The following points are brought out by test results shown on Table I. The slag was removed fairly clean. This is proven by the

fact that the phosphorus increased only 0.001 per cent after the slag was removed. The P_2O_5 content of the finishing slag also checks this point. It is observed that practically no sulphur was eliminated under the oxidizing slag, but under the reducing slag it was eliminated very quickly. The silicon recovery was for practical purposes 100 per cent. The 0.10 per cent addition at the time of removing the slag had gone down to 0.03 per cent within 15 minutes. The test poured just before adding the final ferrosilicon analyzed 0.02 per cent silicon. The final addition was 0.20 per cent and the ladle test was 0.20 per cent. The bath must have been well deoxidized or a loss in silicon would have resulted.

It is not wise to draw too many conclusions from slag analyses. The electric furnace slag is never homogeneous. The slag taken directly under the electrodes contains fewer oxides than that nearer the banks. This slag will also be much higher in CaC_2 than the other slag. The slag may be mixed with a bar and a sample taken, but the results can be of only comparative value. For this reason analyses are best interpreted by one who has been with the heat from the beginning to end and who has taken the samples himself.

CLASS II

Chromium-Vanadium Heat

Table II shows the melting history of a chromium-vanadium heat. This heat was selected because of its simplicity and for the reason that a large quantity of it is produced in electric furnaces today. The practice employed in melting this heat is commonly called "melting with complete reduction." Any alloy steel containing one or more easily oxidized elements may be melted by this method. The discussion which follows is general and may be applied to almost any heat of simple alloy steel.

The Charge

The charge should contain as much of the alloys required by the specifications as are available from the scraps on hand. Proper control of the slag makes it possible to recover practically all of the alloys in the charge. It is always advantageous to do this. Large final additions are undesirable and they are costly. The ability of the electric furnace to conserve such alloys as chromium and vana-

Table II
Chromium-Vanadium Heat—E 2812

	Summary			Per Cent			
	C	Mn	P	S	Si	Cr	V
Estimated in Charge.....	0.95	0.33	0.029	0.03	0.22	1.78	0.16
Determined in test before final additions	0.85	0.30	0.028	....	0.08	1.73	0.15
Taken up to.....	0.93	0.30	0.028	....	0.21	2.00	0.15
Ladle Test	0.92	0.33	0.027	0.017	0.21	1.97	0.15
Specified	0.95	0.35	<.03	<.03	0.22	2.00	0.15
Time	Operation						
4:30-5:00 P. M.	Charging 16,000 pounds of chromium-vanadium scrap, 2000 pounds of high carbon scrap and 400 pounds of lime.						
	Charge in sealed furnace over night.						
5:30 A. M.	Power on—						
7:40 A. M.	Melted test—C 0.85, Mn 0.28, P 0.028, Cr 1.60, V 0.12, slag dark.						
7:43 A. M.	Add 100 pounds lime, 20 pounds 83 per cent Si and 20 pounds of coke.						
7:50 A. M.	Test—C 0.83, Mn 0.30, Cr 1.64, V 0.14, slag dark green.						
8:10 A. M.	Test—C 0.85, Cr 1.69, V 0.14, slag light green.						
8:15 A. M.	Add 25 pounds of coke and 50 pounds of lime.						
8:30 A. M.	Test—C 0.85, Cr 1.73, V 0.15, slag white.						
8:35 A. M.	Add 200 pounds of low phosphorus pig iron, 90 pounds of high carbon ferrochrome.						
9:00 A. M.	Add 10 pounds of ferrochrome.						
9:10 A. M.	Add 15 pounds of coke and 50 pounds of lime.						
9:25 A. M.	Add 46 pounds of FeSi, slag white.						
9:40 A. M.	Tap—partial slag analysis CaO 58.20%, SiO ₂ 24.05%, Cr ₂ O ₃ 0.04%, V ₂ O ₅ Tr. FeO 0.50, slag white.						

dium will undoubtedly be of great importance in the future. The supply of these elements is not unlimited and should be conserved.

A matter of importance in connection with the charge of a heat of this type is the thoroughness with which the scrap is kept separated. One must know the complete analysis of all the scrap charged in order to run the heat intelligently. The carbon content of the scrap is of special importance. The heat must melt fairly close in carbon to the specification or much time will be lost. This point will be emphasized later.

The phosphorus specified has probably the greatest restricting influence on the scrap available for the charge. It is obvious that no dephosphorization takes place in a heat which is run under reducing conditions from the beginning to the end. Thus it is necessary to select scrap with a phosphorus content below that specified. The specification phosphorus less than 0.030 per cent is not difficult to

meet with scrap normally available. It is also practical to melt heats under a reducing slag to meet a specification of phosphorus less than 0.025 per cent but it requires the use of a special low phosphorus scrap, which is expensive. Steels requiring phosphorus less than 0.02 per cent may be made by this method but very seldom are because of the cost of scrap containing phosphorus sufficiently low.

It would be well for more engineers to realize that the chemical composition of a piece of steel does not reveal its complete character. In many cases it is questionable whether steel containing phosphorus less than 0.025 per cent melted under an oxidizing slag and then finished under a reducing slag is superior to a steel containing phosphorus less than 0.03 per cent melted entirely under reducing conditions. The melting practice may have a much greater influence on the quality of the steel than a difference of 0.005 per cent in one of its constituents. It is not meant to infer that it is impossible to produce as high a quality steel when a heat is melted with an oxidizing slag and finished with a reducing slag as when a heat is melted entirely under reducing conditions. Equally sound steel may be made by either method. However, it is probable that a heat which has not been subjected to an oxidizing influence can be more thoroughly deoxidized than one which has been.

The physical condition of the scrap used in this type of heat is of importance. Rusty scrap is used only with risk. The oxide on the scrap may cause the heat to melt low in carbon. It will also make it difficult to obtain a white slag. If coal is added in the charge to counteract the action of the rust the danger of having the heat melt too high in carbon is involved. Scrap which will melt most quickly may be deemed the best. The shorter the time that is consumed in melting, the less erratic will be the results as far as carbon is concerned.

Melting Practice

It is important to have sufficient lime in the original charge. Lack of lime while melting down will result in a black slag, high in oxides, when melted. As the heat melts, spar and a small quantity of sand may be added to make the slag fluid.

Fast melting is an important factor for success in making electric furnace steel. The less time that is required in melting, the less oxide will be found during this operation. The importance of this cannot be overestimated. It is practically the only opportunity for

"making time" without affecting the quality of the final product. In the cases where an exceptionally long time has been required in melting it is generally very difficult to obtain a white slag and time is lost in this way.

When the bath is melted, additions may be made to the slag to deoxidize it. Some materials commonly used for this purpose are carbon, silicon and aluminum. The ideal slag deoxidizer is one which will evolve a large amount of heat in reacting with the oxides in the slag, will unite with a large amount of oxygen and will not contaminate the bath or affect undesirably the physical condition of the slag. Such an alloy has not been discovered as yet but progress is being made in that direction. A combination of several deoxidizers can generally be used more effectively than any single one. The reason for this is that not enough of each one is used to enable it to produce its objectionable effect. Carbon, for example, may be used as the sole slag deoxidizer. However, its action is slow in cases where the slag contains a large amount of oxides. The evolution of large quantities of CO in the slag is not desirable because the bath may absorb this gas. The addition of large quantities of carbon to deoxidize a slag quickly is a hazardous procedure at the best. It may or may not affect the carbon content of the bath, depending on the volume and consistency of the slag. The strong carbide slag is of doubtful value. When such a slag is carried it is very difficult to heat the metal. The slag apparently reflects most of the heat to the roof and walls. This type of slag may be carried on high carbon heats without seriously affecting the carbon content of the bath but cannot be carried on low carbon heats. Regardless of the carbon content of the bath the strong carbide slag introduces an element of chance. There is no reason why a white slag containing a small amount of CaC_2 , namely, under 1 per cent, cannot be effective in deoxidizing the bath. There is an old saying which has yet to be disproved, "You can't have good slag on bad metal."

Silicon in the form of 50 per cent, 83 per cent or 90 per cent ferrosilicon may be used as a slag deoxidizer. Silicon has the disadvantage of making the slag thin. A watery slag will reflect the arc on the roof. The slag, if allowed to become siliceous, will also cut into the banks. Small amounts of silicon may be used to advantage in combination with carbon in treating the slag. It is best to add the silicon first and follow with the carbon. The action of carbon and a thin slag is familiar to all who have seen an electric furnace

heat. It appears to "dry" it. The flat shiny surface changes to puffy rolling slag.

The use of aluminum on the slag of a heat not containing a large amount of oxidizable alloys is not necessary. It is well known that aluminum will thicken up the slag. This property more than counterbalances the advantage it has of being a very efficient deoxidizer. In fact it is too quick a deoxidizer. At furnace temperatures it will unite with oxygen so quickly that a large part of it probably combines with the oxygen available in the furnace before it can reduce the oxides in the slag.

The slag must be fairly well deoxidized before a test can be taken if the specification has narrow limits. If a test is sent before the slag is in good condition, a large increase of chromium or other elements in this bath may occur after the test was taken. Allowing for a large increase in chromium or manganese because of a poor slag involves considerable risk when the limits are close. The correct condition of the slag at this time varies a great deal with the composition of the bath. Naturally, the lower the carbon content, the more difficult it is to obtain a white slag. Other conditions being the same, the iron oxide content of the slag and metal will vary inversely with the carbon content of the bath. It has been observed that iron oxide is more difficult to reduce to a very low figure in the slag than are the oxides of chromium and manganese for instance. Furthermore, a small amount of iron oxide will do much in coloring a slag dark. Thus a slag on a low carbon heat may be sufficiently deoxidized to warrant taking a test before it is white. Careful consideration must be taken of the scrap charge and amounts of slag deoxidizers which have been used before this is done. In the case of heats having a carbon content of 0.30 per cent and over there is normally no reason why a light colored slag should not be obtained before a test is sent.

During the time the test is being analyzed in the laboratory the slag should be made white if it is not already so. This final slag, commonly called a white slag, will vary in color from a pure white to gray and light green. This slag will disintegrate into a fine powder after being exposed to the air for a short time. The cause of this disintegration is difficult to determine. Stansfield suggests that the disintegration of the slag is the result of the change in crystalline form and cooling of mineral silicates high in lime. A slag that crumbles is regarded by some as the *sine qua non*. It is true

that only in rare cases will a poor slag be observed to crumble—but it is not sufficient for a slag to merely crumble to be judged a good slag. The color of the slag is the best indication of its oxide content. It is safe to assume that a pure white slag does not contain a large amount of iron oxide.

The importance of obtaining a white slag and maintaining it for a considerable length of time cannot be over-estimated. There is no advantage in making steel in the electric furnace if the slag is not thoroughly deoxidized. The same quality steel might be achieved in the basic open-hearth. The electric furnace cannot produce high quality steel without careful supervision of the slag condition.

The best rule to follow in regard to additions of any kind is to make them as early as possible. In any heat of this type practically everything but the silicon may be added as soon as the result of the carbon test is known. The estimate of the charge enables one to do this. For instance, if the chromium in the charge estimated 1.70 per cent and 2.00 per cent is desired, it is perfectly safe to add 0.25 per cent of ferrochromium of suitable carbon content as soon as the carbon of the bath is known. It is important that the finals be given a considerable length of time in the furnace.

The finals in Heat E 2812 shown in Table II were added as early as they might have been. In normal practice the only test sent to the laboratory would have been the test taken at 8:10 A. M. When the carbon on this test was reported, 200 pounds of pig iron and 90 pounds of ferrochromium were added. Thus the only further addition necessary was 10 pounds of ferrochromium added when the chromium was reported.

Often in heats of this type a large portion of the silicon originally in the charge is carried through the entire heat. In some cases as much as 0.15 and 0.20 per cent is present in a bath melted from scrap containing 0.22 per cent silicon. The amount of silicon present in the bath is very difficult to judge by pouring tests. A great deal of judgment must be used in the amount of silicon that is added if accurate results are to be obtained. In this connection standard charges aid the melter in his judgment. If the specification for silicon is particularly important it may be advisable to have a silicon test run. It may be noted in Table II that only 0.13 per cent of ferrosilicon was added to Heat E 2812 and the ladle test contained 0.21 per cent. It is interesting to note the increase of chromium and vanadium in the bath as the slag becomes light in color.

All the foregoing discussion has been based on the assumption that the carbon of the bath was near enough that desired when the bath was melted. In the event that the carbon is too low, the slag must be removed and coal added to raise the carbon. This exposes the metal to the air and involves a loss in time. In the case of the carbon being too high the heat may be termed a failure. Adding ore to lower the carbon is the most objectionable thing that can be done to such a heat. A large loss of chromium and vanadium will result and the bath may become oxidized to such an extent that the final slag may not be able to deoxidize it.

The practice of dipping the electrodes into the metal, as a means of raising the carbon, has not been discussed. Except in very rare cases there is no excuse for resorting to this method. The results that are obtained by this method are so inconsistent that it is not used by most furnace operators.

CLASS III

HIGH SPEED HEAT

Slag analyses are shown in Table III. Due to the high oxide content of the slag when the bath is melted, slag analyses are of special interest. It has been stated before that the slag in the electric furnace is not homogeneous and for that reason slag analyses can be accepted only for what they are, merely an approximation of the true slag composition.

No reference is necessary to the melting practice used in melting the high speed steel or to the scrap charge. The same principles brought out in connection with the chromium-vanadium heat may be applied. The only difference might be the necessity for a stronger reducing condition due to the high percentage of oxides in the slag when the heat is melted. However, this is largely a question of the physical condition of the scrap. Scrap of unusual cleanliness will melt down with a slag that is very easily made white.

It is interesting to note in Table III that in 25 minutes the slag is comparatively free of all oxides with the exception of V_2O_5 . The V_2O_5 is much more slowly reduced than are the other oxides. It will be noted that WO_3 is reduced more quickly and completely than the others. The recovery of vanadium on this heat was not poor. Assuming the slag to weigh 1,000 pounds the recovery is 94 per cent.

Every heat of this type is a problem in itself and must be dealt

Table III
High Speed Steel Slag Analyses—E 2674

Time	C 0.60	Mn 0.30	P 0.027	Estimate of Charge				V 0.67	W 18.90
				S 0.03 Cr ₂ O ₃	Si 0.20 WO ₃	Cr 2.90 V ₂ O ₅	FeO		
		Operation						Color	
3:20		Melted							
3:25		Slag sample		2.62	4.10	4.47	4.46	Black	
3:26		Add slag deoxidizers							
3:35		Slag sample		1.31	2.20	3.84	1.88	dark green	
3:40		Add Coke							
3:50		Slag sample		0.98	0.40	3.25	0.81	light green	
4:10		FeCr and FeV added							
4:35		Slag sample		0.15	0.20	2.40	0.81	almost white	
4:50		Coke added							
5:15		Slag sample		0.05	tr	2.30	0.58	white	
5:16		Add FeSi							
5:31		Tapping Slag		0.04	tr	1.50	0.38	white	

Slag samples were taken from a bar which in each case was swept across entire slag surface.

with accordingly. No general rule can be made unless it is to get the slag white as soon as possible and keep it white until the heat taps.

The chief reason for showing the slag analyses on this heat is to illustrate the practicability of deoxidizing thoroughly a slag very high in oxides. The two benefits obtained are the alloys from the slag and protection of the metal. Removing the slag resulting in exposure of the bath to the air can have only ill effects.

As in the case of the chromium-vanadium heat, the estimate of the charge is very useful. It will greatly expedite the addition of finals. It will also aid one in judging the possible increase of an element after the test is sent. The necessity of having the slag fairly well deoxidized before a test is sent to the laboratory is obvious.

GENERAL SUMMARY

Carbon Tool Heat

1. The carbon in the charge should approximate the desired carbon.
2. The establishment of a strong oxidizing condition is not necessary but harmful. The presence of sufficient lime is necessary to prevent reduction of phosphorus from the slag into the metal.

3. The oxidizing slag should be removed as clean as possible.
4. The carbon when melted should be near the desired carbon to avoid the use of a large quantity of coal in raising the carbon.
5. The bath should be well deoxidized before tapping by maintaining a white slag slightly carbide.

Chromium-Vanadium Heat

1. The charge should contain practically all the alloys specified. The alloying elements may thus be gained from scrap and their presence in the charge will reduce the amount of final additions.
2. It is important that the slag is fairly well deoxidized before a test is sent to the laboratory if accurate results are to be expected.
3. The slag should be made white and kept white for a considerable time to insure the bath being deoxidized to a high degree.
4. Finals should be added as early as possible so that they will be in the furnace the maximum time before tapping.

High Speed Heat

1. All points brought out in connection with chromium-vanadium heat are applicable here.
2. A reliable estimate of the charge is very useful in heats of this type.
3. In spite of the high alloy content of this steel the slag can be deoxidized to a high degree.

CONCLUSION

It may be noted that no reference was made in this paper to bath temperatures. This was purposely omitted. The problem of correct tapping temperatures for various classes of steel is one so involved that it would constitute a paper in itself. Pouring problems are also omitted. The intended use of the steel decides the pouring practice. Some steel must be top poured to successfully meet its requirements and some must be bottom poured. This can be determined only by experience. In many cases steels of the same composition must be poured by various methods in order to be successfully finished into different products.

In regard to bath temperatures of simple alloy steels the generalization might be made that the metal should be gotten "hot." "Cold" heats very often give trouble. It is good practice to tap "hot" and

hold the heat in the ladle for a sufficient length of time to cool to the proper temperature.

The writer wishes to express his appreciation to J. A. Wiley, chief chemist of The Midvale Company, for his co-operation in making the slag and metal analyses.

DISCUSSION

H. M. GERMAN¹: On page 578 the writer states that fast melting is an important factor for success in making electric furnace steel. The less time that is required in melting, the less oxide will be found during this operation. That statement, I think, is very apt to be misleading. Those of you who have had experience in operating under low voltages and then have had the furnaces changed over to the high voltages, I think will agree with me. At the start of the melting period the electrodes bore down through the charge and form at first just a very small pool of metal. If high power is applied there is no question that there will be formed a small pool of superheated steel. The power input of a furnace during melting should not be faster than what can be radiated away by the stock. If the bath becomes superheated below the point of the electrode, I do not think there is any question that at this high temperature, particularly when using the very high voltages, that there is an additional reaction due to the action of the electric arc on the atmosphere in the furnace. What happens is that the air is dissociated into nitrogen and oxygen, and there will be an absorption of nitrogen by the bath of metal and with oxygen present iron oxides will be formed which will also be absorbed. This has clearly been brought to our attention, by a manufacturer of steel castings, a short time ago, when they had trouble with their regulator and were able to put in considerable more voltage and current than they desired. The resulting castings were full of blow holes. After they had located the trouble and supplied the proper amount of voltage the blow holes disappeared. That is the one point which I think that furnace men should take into consideration, as I stated first that those of us who have had to change over from a low tonnage to a high tonnage have experienced a certain amount of trouble due to too rapid melting.

Author's Closure

The condition which Mr. German suggests might be due to the pool of metal becoming superheated could occur on low voltage as well as with high voltage. Improper placing of the charge in the furnace can easily cause superheating. If the scrap is charged correctly, the pool of metal will be constantly dissolving more scrap. "Superheating" of the pool, if it does occur when using high voltage, should leave its mark on the furnace bottom. We have never had a bad bottom due to this cause.

The point in regard to the absorption of nitrogen is very interesting. Specific data in this connection would be generally welcomed.

It should be borne in mind that metal must be superheated, for a few moments at least, if it is being melted by an electric arc.

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Recommended Practice Committee Releases*

CONSTITUTION OF MAGNESIUM-ZINC ALLOYS†

By J. A. Gann and A. W. Winston‡

THE first investigation of the entire magnesium-zinc system of alloys is attributed to Boudouard.¹ He established the existence of the compound $MgZn_2$ by means of cooling curves and attempted to explain certain microscopical and analytical data on the assumption of the formation of the compound Mg_2Zn . Grube,² Bruni and associates,³ and Eger⁴ confirmed the work of Boudouard except for the formation of the compound Mg_2Zn . More recent investigations by Chadwick⁵ and Hume-Rothery and Rounsefell⁶ have substantially confirmed the liquidus of the earlier investigators, but have completely revised the solidus, particularly in the zinc-rich alloys, where several new compounds and peritectic reactions have been discovered.

Grube and Burkhardt⁷ have conducted exhaustive researches on the electrical conductivity, thermal expansion, and hardness of the magnesium-zinc alloys. Their findings corroborate in general the thermal analysis and microscopic data referred to above, particularly in the magnesium-rich alloys.

Kremann and Müller⁸ studied the electromotive force of magnesium-zinc alloys and concluded that the addition of zinc makes magnesium more noble, probably due to the formation of solid solutions. This work was not sufficiently complete to permit drawing definite conclusions.

Based on microscopical evidence and mechanical property determinations, Stoughton and Miyake⁹ concluded that approximately 10 per cent of zinc is soluble in magnesium at the eutectic temperature and that this solubility decreases with lowering temperatures. Schmidt¹⁰ has made a more detailed study of the solid solubility of zinc in magnesium. He substantially confirms Chadwick's⁵ values at 250 degrees Cent., and shows that this solubility decreases to 2.0 per cent at 100 degrees Cent., but obtains a maximum solubility of only 6.0 per cent at the eutectic temperature. In studying the age-hardening of magnesium-zinc alloys, Meissner¹¹ likewise concludes that approximately 2.0 per cent zinc is soluble in magnesium at room temperature. Confirmed by Gann.¹²

Fig. 1 shows the constitutional diagram of the magnesium-rich alloys according to Hume-Rothery and Rounsefell⁶ modified to agree with the results of Schmidt.¹⁰ This portion of the diagram shows a simple eutectiferous system of alloys except for the solid solubility of zinc in magnesium, and hence calls for no special explanation.

†This data sheet deals primarily with the magnesium-rich alloys. The zinc-rich alloys are discussed by W. M. Peirce in another data sheet entitled, "Constitution of Zinc-Magnesium Alloys." The references cover the entire system.

‡Metallurgists, The Dow Chemical Company, Midland, Mich.

*The releases from the Recommended Practice Committee as printed here with will be included in the next edition of the A. S. S. T. HANDBOOK, which will be published about June 1, 1930.

Magnesium alloys containing low percentages of zinc, with or without the presence of a small addition of aluminum, are used in Europe, both for castings and mechanically worked parts. Wrought alloys usually contain less than 5.0

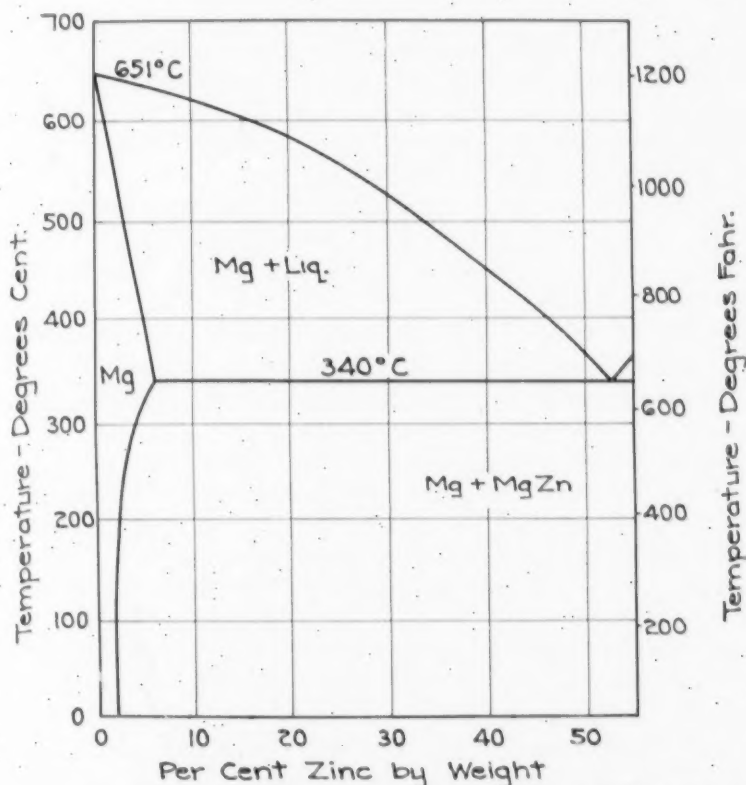


Fig. 1—Magnesium-Zinc Equilibrium Diagram (Hume-Rothery and Rounsefell modified by Schmidt).

per cent zinc since increasing the zinc content likewise increases brittleness. In cast alloys, the percentage of zinc may be somewhat higher, although it is customary to add a little aluminum rather than additional zinc. Alloys containing more than 2.0 per cent zinc are subject to improvement by age-hardening.

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- ¹³G. Tammann, *Ztsch. f. anorg. Chem.*, 1915, v. 92, p. 76.
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- ¹⁵W. M. Peirce, *A. I. M. E. Trans.*, 1923, v. 68, p. 767.
- ¹⁶J. B. Friauf, *Phy. Rev.*, 1927, v. 29, ser. 2, p. 34.
- ¹⁷Hajime Koto, *Mem. Coll. Sci. Kyoto Imp. Univ.*, 1929, v. 12A, p. 81; *C. A.* 1929, v. 23, p. 4174.
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MECHANISM OF CARBURIZATION*

Purpose of Carburizing—The purpose of carburizing is to obtain through the penetration of carbon, in the article subjected to the process, an outside portion high in carbon, generally known as the case, and which gradually decreases in carbon content towards the center of the piece. After suitable heat treatment, this case is hard and resistant to wear.

Hardness—In general the hardness of the case as measured by the scleroscope or Rockwell tests, depends upon the carbon concentration, kind of steel, and the heat treatments after carburizing.

The addition of certain alloys, especially chromium, will give a harder case than the plain carbon steels. The hardness also depends upon the mass of the article, quenching temperature, quenching medium, and the temperature of the quenching medium.

Resistance to Wear—The resistance to wear will depend upon the hardness obtained and also upon the composition of the steel. The carburized alloy steels usually give greater wear resistance than the carburized plain carbon steels under similar conditions of service.

Carbon Content of Case—The carbon content of the case ranges from hypereutectoid (above 0.90 per cent carbon) at the surface through the eutectoid (approximately 0.90 per cent carbon) to the composition of the core (original carbon in steel). The carbon concentration, both at the surface and on through the case, will depend upon the materials employed and the carburizing practice.

Any increase in carbon above that of the core which on subsequent heat treatments will produce an appreciable change in structure over that of the core should be considered the case.

Ductility of the Core—The core may be improved by heat treatment provided that the heat treatment which follows carburizing was properly selected and performed.

Carburizing Steels—The steels used for carburizing are given throughout the carburizing section of the A.S.S.T. Handbook.

Effect of Alloy Elements—The alloying elements in carburizing steel may be divided according to their behavior toward carbon, as follows:

1. Carbide forming elements
2. Other than carbide forming elements.

As an example of the first class chromium and manganese should be mentioned, while nickel belongs to the second class. Certain elements such as, for instance, manganese and vanadium may be present either as carbides or in a form of solid solution with iron. This is particularly true of vanadium, which is found partly associated with pearlite (as a vanadium or vanadium-iron carbide) and partly dissolved in the ferrite.

The carbide forming elements impart hardness and wear resistance to the case and often strengthen the core. Nickel, molybdenum, and vanadium

*A report of the Sub-Committee on the Mechanism of Carburization of the Recommended Practice Committee of the A. S. S. T. The membership of the Sub-Committee was as follows: Dr. V. N. Krivobok, Chairman, W. B. Crowe, W. I. McInerney, and Dr. C. H. Herty, Jr.

impart strength and toughness to the core. Certain elements, as for example nickel, lower the critical transformation in carburized steels, especially so in the case which permits lower quenching temperatures.

Theory of the Carburizing Process—It is generally conceded that the carburizing process implies two distinct steps: (a) degasification of the carburizing mixture and the formation of a compound between carbon and oxygen and (b) interreaction between the latter compound and the iron of steels.

In the articles subjected to carburizing, carbon does not exist as such but is found in the form of an iron carbide¹ of the formulae Fe_3C . Consequently the process of carburizing consists of two distinct processes:

1. Formation of iron carbides
2. Absorption of iron carbide by the steel.

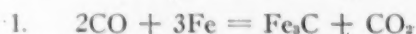
Both processes require a high temperature for their completion, although the formation of iron carbide can be accomplished at the temperatures below the critical range.

For the absorption of the formed iron carbide the heating for a certain length of time at temperatures often 200 to 300 degrees Fahr. above the critical range is essential. The reason is that alpha iron, an allotropic form of iron in existence below the critical temperatures, possesses but a very limited capacity for dissolving carbides, while gamma iron, another allotropic form of iron which is found at temperatures above the critical range, can hold in solution as much as 1.7 to 1.8 per cent carbon.

Therefore, steels heated to high heats dissolve iron carbide forming a solid solution between it and the gamma iron of steels. On subsequent slow cooling to room temperature iron carbide is liberated and is found as either structurally free or as an essential part of pearlite.

Formation of Iron Carbide—The carburizing compound is in reality the "gas producer" for carbon monoxide and possibly carbon-nitrogen compounds. These gases actually do the work of carburizing.

The carbon monoxide is derived from the partial combustion of the carbonaceous packing compound by the oxygen from the air. Upon formation this carbon monoxide gives its carbon to iron according to the reaction:



the resulting Fe_3C being dissolved in gamma iron.

The CO_2 gas, however, cannot remain as such at high temperature² when in the presence of the excess amount of carbonaceous packing or carburizing compound. It will react with carbon in the following way:



This reaction is another source of carbon monoxide. The cycle of reactions, as just described, goes on repeating itself during the whole time that the process of carburizing goes on.

¹The opinion of many that carbon is atomically dispersed is recognized, but in this article it is assumed that the carbon forms iron-carbide, Fe_3C , which is dissolved in gamma-iron.

²There is a definite equilibrium between CO_2 , CO , and C , in which the percentage of CO_2 decreases as the temperature rises.

Most of the carburizing compounds that are on the market at the present time contain so-called energizers. These energizers are mostly carbonates, such as soda ash (sodium carbonate), limestone (calcium carbonate), and barium carbonate, which are usually used in admixtures of different proportions. The role of the energizers is not altogether clear. At the high heat of carburizing the energizers break up producing carbon dioxide in accordance with the simple reaction as follows:



CO₂ cannot exist in the presence of solid red hot carbonaceous packing and forms carbon monoxide gas.

4. $\text{CO}_2 + \text{C} = 2\text{CO}$, which in turn reacts with iron as explained under reaction (1). It may also be that under certain conditions the energizers decompose producing directly carbon monoxide possibly in accordance with the following reaction:



It is believed that the oxide (XO) resulting from the decomposition of energizers (see reaction 3) acts as a catalyst in the reaction between carbon monoxide and iron of steel (reaction 1).

Absorption of Iron Carbide by Steel—At the high temperature of carburizing, the iron of the steels exists in the allotropic form of gamma iron. As stated previously, gamma iron is capable of holding in solution as much as 1.7 to 1.8 per cent carbon. In consequence of this the iron carbide formed in accordance with reaction (1) is dissolved in gamma iron.¹ The amount of carbon introduced into the carburized case is usually about 1.0 per cent or slightly higher. As long as the temperature of the steel remains above the critical range this carbon is held in solid solution, in all probability as Fe₃C and not as carbon proper. When the upper critical transformation is reached, when cooling carburized articles, all the carbon in excess of 0.90 per cent, for carbon steels, is precipitated. When the article is finally cooled to room temperature, the carbon is found as cementite or iron carbide, sometimes located at grain boundaries and sometimes in large agglomerated patches. The 0.90 per cent carbon is held in the solid solution until the A₁ transformation is reached (approximately 1340 degrees Fahr.). At this temperature the solid solution containing 0.90 per cent carbon is bodily converted into an intimate mixture of ferrite and cementite and is known as pearlite.²

Consequently the carburized layer upon cooling to room temperature consists of pearlite plus cementite, pearlite, and pearlite plus ferrite. It is sometimes observed that the steels carburized apparently under identical conditions present different metallographic appearance when viewed under the microscope. The difference is mostly in the appearance and the distribution of cementite constituent of the carburized case. In the majority of cases it is found as straight needles intersecting the pearlitic grains and also form-

¹See footnote 1 on second page of article.

²The eutectoid composition may be as low as about 0.70 per cent carbon in some of the alloy carburizing steels.

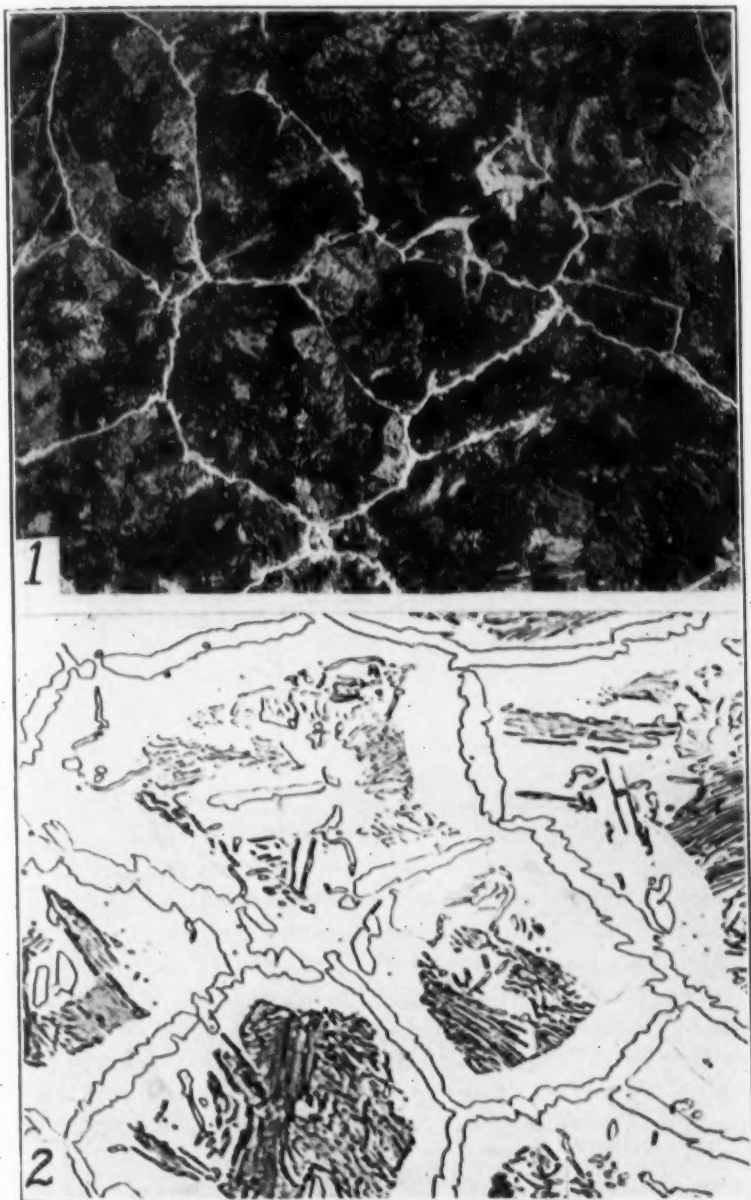


Fig. 1—Carburized Case of Finely Divided Pearlite Grains Which are Surrounded by Thin Cementite Boundaries. $\times 300$.

Fig. 2—Carburized Case With Thick Cementite Grain Boundaries and Within the Grains Islands of Coarse Pearlite in Ferrite. $\times 300$.

ing a thin layer separating one pearlitic grain from another. Such a structure after carburizing is satisfactory and is represented in Fig. 1. On the other hand, a very different structure is sometimes obtained. The cementite of the carburized part is found in obvious predominance and forms very thick envelopes around pearlitic grains. It is accompanied by the areas of ferrite

immediately adjacent to cementite. The grains are large and the structure of pearlitic grains proper is very coarse. This structure is not satisfactory and is shown in Fig. 2.

General Carburizing Processes—The carburizing process is sometimes accomplished with the use of either liquid or gaseous mixtures. In all cases the theory of the process is essentially the same, being, quite naturally, more complicated in such special processes as the cyanide bath method of carburizing, where a substantial penetration of nitrogen as well as carbon is obtained.

Solid Carburizing Compounds—The various solid compounds for carburizing are numerous. The base materials for many of the compounds are: charred wood, bone, leather, petroleum coke or other carbonaceous materials. These materials are usually sized, ground, or otherwise prepared and mixed with an energizer.

The work to be carburized is generally packed in boxes or pots, with sufficient carburizer to properly cover the work (1 inch spaces around parts are desirable for general practice). The work is then heated to a temperature and held for a time which has been predetermined to give the desired carbon absorption. The carburized articles may be cooled in the boxes or shaken out of the carburizer while still hot. The method of cooling depends upon the subsequent heat treatments and the type of product desired.

Another method of carburizing is to place in the container a certain amount of compound for each pound of steel charged so that when the process is completed the carburizer is entirely spent. With this method a fresh mixture is used for each run.

Gas Carburizing—The carburizing gas is usually generated apart from the container and conveyed to the container which is maintained at the carburizing temperature. The container must be so designed that free circulation of the gas is possible. If the container is of a sufficient size, the flow of the gas should be reversed periodically to insure uniform absorption. In this process suitable fixtures are used to prevent mechanical damage, such as warpage. Besides the various carbon rich artificially prepared gases, natural gas is also used in some localities in gas carburizing machines.

Carburizing with Liquid Compounds—A liquid carburizer (cyanide compounds) in the molten state when maintained at a temperature of approximately 1450 to 1500 degrees Fahr. produces only a slight depth of carbon penetration.

Heat Treatments Required After Carburizing—The relative cross sectional area of the case and core and the use to which the part is to be put determines the advisability of refining the core before finally hardening the case.⁴

Elimination of Soft Spots—Soft spots are usually traceable to steel of inferior quality, decarburization of some area that might have been previously properly carburized, poor carburizer or carburizing practice, method of heating for quenching, and finally the application of the cooling medium in the

⁴See the article on Carburizing and Heat Treating of Carburized Steels in the A.S.S.T. Handbook.

quenching operation. Areas that have been uniformly hard may be cracked or softened by local over-heating in grinding.

Processes Other than the Process of Cementation with Carbon—

Nitrogenizing and other processes such as the penetration with pulverized ferrochromium and ferromanganese applied in paste form on the inside of the mould in making castings are attracting attention.

Depth of Case—The depth of case obtained depends on the time, temperature, and activity of the carburizing mixture. For a guide refer to the article entitled Carburizing Table in the A.S.S.T. Handbook.

LINEAR EXPANSION OF S. A. E. STEELS

By Floyd C. Kelley*

S.A.E. Steels	C	Mn	Cr	Ni	V	W	Condition of Steel	Temp. Degrees Fahr.	Coefficient of Linear Expansion [†]	
1010	.14	.39	...	...	...	...	.....	59- 167	.0000066	Honda
1020	.18	.34	...	...	...	...	.....	59- 167	.000006727	Int. Crit. Tables
1030	.31	.65	...	...	...	...	.....	59- 167	.000006517	Int. Crit. Tables
1045	.44	.67	...	...	...	...	.....	59- 167	.000006472	Int. Crit. Tables
1095	.94	.35	...	...	...	...	.....	59- 167	.00000639	Honda
2330	.33	.78	...	3.59	...	...	Annealed	{ 77- 572 572-1112	.00000672 .0000085	Sunder and Hindert
3250	.50	.64	.88	1.90	...	...	.....	{ 77- 212 77- 518	.00000651 .000007055	Mathews
3335	.32	.53	1.37	3.53	...	...	Quenched from 1525° F. Tempered at 1050° F.	{ 77- 212 77- 518	.000006572 .0000071	Mathews
3435	.35	.65	.80	3.14	...	...	Quenched from 1550° F. Tempered at 1050° F.	{ 77- 212 77- 518	.000006516 .000007105	Mathews
3140	.43	.78	.75	1.87	...	...	.....	{ 77- 212 77- 518	.00000666 .00000715	Mathews
6135	.34	.72	.96	...	.17	...	Quenched from 1700° F. Tempered at 1150° F.	{ 77- 212 77- 518	.000006533 .000007277	Mathews
71360	.73	...	3.90	...	...	13.50	.....	{ 212 392 572	.000005944 .000006528 .000007083	Honda

*General Electric Co., Research Laboratory, Schenectady, N. Y.

[†]Cubical expansion may be obtained with sufficient accuracy by multiplying linear expansion by 3. Coefficient of linear expansion per degree Cent. = coefficient per degree Fahr. $\times 9/5$.

Comment and Discussion

Discussion of the Paper by Lawford H. Fry on "Locomotive Forgings"

By G. F. Cunningham²

TO one who has considerable to do with the testing of locomotive forgings and castings, Mr. Fry's paper on "Locomotive Forgings" and the discussion appended thereto was of considerable interest to me.

The most striking point about this and most papers on like subjects, all stress appears to be placed upon static tension tests as determining the suitability of the material for certain applications. In dealing with locomotives do

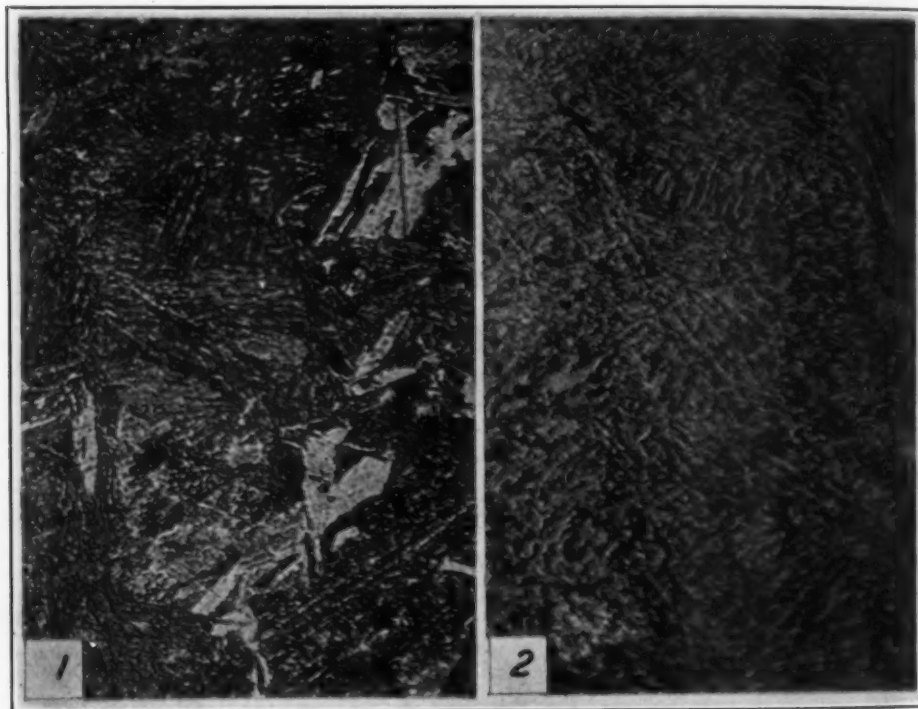


Fig. 1—Chromium-Nickel Steel Axle which Failed in Service. $\times 500$.

Fig. 2—Chromium-Nickel Steel Axle after Heat Treatment (1500 Degrees Fahr. Quenched, 1100 Degrees Fahr. Temper—Cooled Fairly Fast.) $\times 500$.

	Fig. 1	Fig. 2
Ultimate Strength	179,000	140,500
Elastic Limit		125,000
Elongation 2 Inches	11.5%	20.5%
Reduction of Area	44.3%	59.6%
Izod Impact	12 ft. lbs.	84 ft. lbs.
Brinell	340	262

¹Lawford H. Fry, "Locomotive Forgings," TRANSACTIONS, American Society for Steel Treating, Vol. 17, January, 1930, p. 1.

²G. F. Cunningham, member of the society, superintendent of testing laboratories, University of Manitoba, Winnipeg, Canada.

we know that resistance to tensile strains (which of course, are the most accurate to determine) is the only property that we should consider. The writer believes that impact values are often the cause of failure. This also controls possible fatigue values and reduces the endurance limits considerably.

We know that tensile properties are the most easily obtained by heat treatment, but resistance to impact is not necessarily the result of good tensile values.

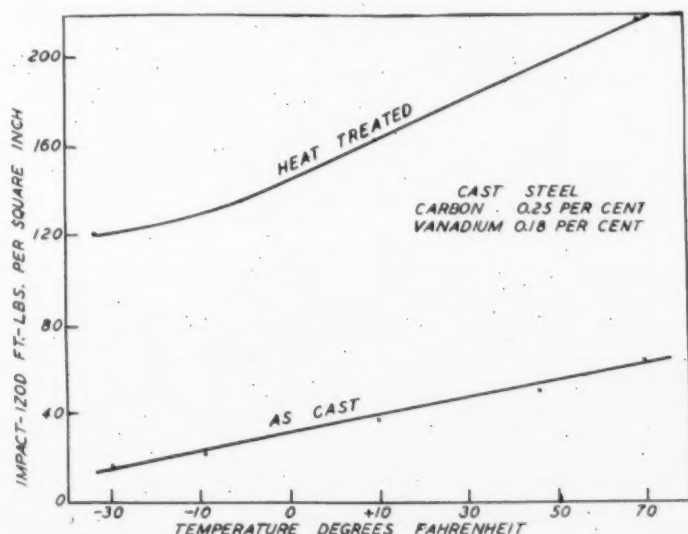


Fig. 3—Impact Tests Made on a 0.25 Per Cent Carbon—0.18 Per Cent Vanadium Cast Steel Over a Range of Temperatures (−30 to + 70 degrees Fahr.) Winter of 1929-30.

Tests show that the two properties are not dependent upon one another and the writer has noticed many specimens which pass the tensile test with flying colors but which are exceptionally poor in impact properties.

After heat treatment to obtain fine structure, tensile values are possibly lowered somewhat but may still be above the minimum desired while the impact value has been increased as much as 12 times. (Figs. 1 and 2)

Charles McKnight and H. A. F. Campbell seem to be the only ones who mention this toughness value in the discussion.

I may be on very thin ice, but this seems to me a very vital point, especially in countries such as our own, where temperatures go down to minus 40 degrees Fahr. in the winter. One can see what this means by the curve (Fig. 3) which the writer obtained showing what low temperature will do to some of our metals.

I believe we should refer more often to the closing of Chapter XII of Sauveur's "Heat Treatment and Metallography of Steel and Iron."

Articles such as Mr. Fry's cannot do other than still further advance the great improvements the steel making and treating men have made in the materials they use and this in spite of the added abuse in fabrication and service which always keeps one jump ahead as it does in everything we do today.

THE ENGINEERING INDEX

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In the preparation of the Engineering Index by the staff of the American Society of Mechanical Engineers some 1700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. is supplied with this selective index to those articles which deal particularly with steel treating and related subjects.

AIRPLANE MATERIALS

MAGNESIUM ALLOYS. Magnesium and Its Alloys in Aircraft, W. G. Harvey. *Metal Industry (Lond.)*, vol. 35, no. 26, Dec. 27, 1929, pp. 615-617.

Magnesium metal is one-third lighter than aluminum, and is used in airplane construction; due to its inherent chemical and mechanical characteristics, it has been difficult to work metal into useful shapes; recently, through discovery of methods of purification of metal and of heat treatment of magnesium alloys, most fabricating obstacles have been overcome; mechanical properties. Paper presented before Am. Electrochem. Soc., previously indexed from Advance Paper, for mtg. Sept. 19-21, 1929.

METALS. The Development of Metals for Aircraft Purposes, Rosenhain. *Aeroplane (Lond.)*, vol. 37, no. 26, Dec. 25, 1929, (*Aeronautical Eng. Supp.*) pp. 1434 and (discussion) 1436.

General trend in development of metals for airplane is given with estimation of present direction and future tendencies; various steels, aluminum alloys, and very light alloys such as those based on magnesium are considered in regard to strength-weight ratio, stiffness, resistance to fatigue, to wear, and to corrosion, strength at high temperatures, and ease of working. Abstract of paper presented before Roy. Aeronautical Soc.

AIRPLANES

CORROSION PREVENTION. Combating Corrosion of Aircraft Metal Parts, J. E. Sullivan. *Aviation*, vol. 28, no. 5, Feb. 1, 1930, pp. 201-204, 4 figs.

Detailed discussion of preparing metal surfaces, proper coating, inspection and maintenance to insure adequate protection against possible structural failure due to corrosion; variety of aircraft finishes discussed; process for protecting duralumin developed by pioneer aircraft manufacturers in cooperation with Navy Department and Aluminum Corp. of America; suggestions for reducing to minimum evils of corrosion.

ALLOY STEEL

Rising Tide of Alloy Steels Finds Producers Eager for Action, J. D. Knox. *Iron Trade Rev.*, vol. 86, no. 1, Jan. 2, 1930, pp. 14-18, 3 figs.

Applications of alloy steel in 1929 are

discussed; having introduced numerous new brands, makers of corrosion and heat-resisting and cutting materials now turn to marketing and production problems; list of trade names of alloy steel is given.

Some Lesser-Known Facts Concerning Alloy Steels, J. H. Andrew. *Mech. World (Manchester)*, vol. 87, no. 2245, Jan. 10, 1930, pp. 37-39, 5 figs.

Consideration of forging and heat-treating problems beginning with raw ingot, in as-cast state; peculiar structure of steel; test results which show that except for sealing up blowholes and small cavities, operation of hot forging has not quite redeeming features usually attached to it; alloying elements in some way affect conditions of carbide. (To be continued.) Abstract of paper presented before Instn. Engrs. and Shipbldrs.

Notes on Alloy Steels, J. H. Andrew. *Foundry Trade J. (Lond.)*, vol. 41, no. 694, Dec. 5, 1929, pp. 411-412.

Some lesser-known facts concerning alloy steels are discussed; advantages associated with hot work; constitution and mechanical strength; formation of carbides; choice of alloy steels; depth hardness; temper brittleness; quenching temperatures; influence of rate of cooling on fracture. Abstract of paper presented before Instn. of Engrs. and Shipbldrs. in Scotland.

ALLOY STEEL CASTINGS

Compares Properties of Various Alloy Steel Castings, D. Zuege. *Foundry*, vol. 58, nos. 1 and 2, Jan. 1, pp. 100-103 and Jan. 15, 1930, pp. 71-74, 5 figs.

Jan. 1: Data relating to alloy steels adapted to foundry use; classification; characteristic effects of chromium, nickel, manganese, vanadium, and molybdenum upon structure of steel; comparison of chrome-nickel and manganese carbon steel. Jan. 15: Physical characteristics for casting purposes compared; reactions of different steels for various heat treatments; agreement between structure and properties. Indexed in Engineering Index 1929, from Am. Foundrymen Assn.—Preprint.

ALUMINUM ALLOYS

Aluminum and Aluminum Alloys, S. Tour. *Min. and Met.*, vol. 11, no. 277, Jan. 1930, pp. 7-8.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders.

Use of aluminum alloys for building railroad cars has led to production of large structural shapes, up to 14 in. in depth and 90 ft. long; casting of 200 to 300-lb. ingots; use of aluminum to resist corrosion; X-ray inspection of aluminum castings and forgings; die-casting alloys. Bibliography.

CORROSION. Protection of High-Strength Light Alloys Against Corrosion (La protection des alliages légers a haute resistance contre la corrosion), M. Marchies. *Technique du Bureau Veritas—Bul. (Paris)*, vol. 11, no. 12, Dec. 1929, pp. 258-259.

Type of alloys dealt with are aluminum alloys, such as duralumin, containing 94 to 95 per cent aluminum, specific gravity of which is below 3 tons per cu. m., and tensile strength equal to that of mild steel; discussion of corrosion and its prevention.

SILUMIN. Aluminum Alloys (Der neue Silumin-Katalog). *Automobiltechnische Zeit. (Berlin)*, vol. 32, no. 33, Nov. 30, 1929, p. 769.

Though named catalogue, this publication gives scientific treatise on modern methods and uses of aluminum alloys; it discusses metallurgy of aluminum alloys, shows microscopic and macroscopic photographs, gives physical and chemical qualities with reference to modern strength and corrosion requirements, etc.; book has been ordered for class-room purposes by several technical universities.

AUTOMOBILE MANUFACTURE

NITRIDING. Nitriding Investigations, R. Sergeson. *Soc. Automotive Engrs. J.*, vol. 26, no. 1, Jan. 1930, pp. 110-111.

Résumé of developments of nitralloy and nitriding process; results obtained by nitriding compared with those obtained by carburizing effects of various temperatures during nitriding process; furnaces, methods and results; nitriding increases strength of steel.

AUTOMOBILE MATERIALS

METALS TESTING. The Institution of Automobile Engineers, L. W. Johnson. *Automobile Engr. (Lond.)*, vol. 19, no. 262, Dec. 1929, pp. 511-518, 15 figs.

Review of various types of materials tests available and different kinds of defects that may be encountered in metals and their alloys; supply and identification of material; types of tests including tensile, Brinell hardness, impact, fracture, bend and reverse bend, torsion, fatigue, magnetic, pickling and etching, sulphur prints, and macro-etching tests; checking bar material, castings, tubes and wires.

BERYLLIUM

Beryllium as a Possible Structural Metal, C. B. Sawyer. *Soc. Automotive Engrs. J.*, vol. 26, no. 1, Jan. 1930, p. 98.

Beryllium has peculiar combination of properties to justify most serious engineering attention; very low density; strength high and comparable to that of steel; as structural metal it still has one serious fault as it lacks ductility; composition of beryl is such that it reminds one of clay with part of its aluminum oxide replaced by beryllium oxide.

BRASS ANNEALING

Penetration of Heat in Annealing Mass with Annealing of Brass Sheets (Das Eindringen der Waerme in die Gluehhaufen beim Ausgluehen von Messingblechen), W. Roth. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 12, Dec. 1929, pp. 414-415, 8 figs.

Report of practical tests of cementation of 3000, 1000, and 1270 kg. brass sheets in annealing furnace under different operating conditions; temperature curve for annealing during several hours; conclusions.

BRASS RESEARCH

Stress-Corrosion Cracking of Annealed Brasses, A. Morris. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 263, Feb. 1930, 15 pp., 9 figs.

Coarse grain in so-called "high brasses" appears to lower resistance of piece to stress-corrosion attack; lead and tin tend to make alpha brass less resistant to this form of attack; resistance of Muntz metal, naval brass, manganese bronze is increased by quenching from low annealing temperature; results are presented to promote discussion.

CAST IRON

EXPANSION. Expansion Coefficients of Cast Iron (Beitrag zum Ausdehnungs Koeffizienten des Gusseisens), F. Roll. *Gieserei Zeitung (Berlin)*, vol. 27, no. 1, Jan. 1, 1930, pp. 4-7, 11 figs.

Brief notes of structure of metals, after which author explains relation of expansion to structural constituents, and relations of expansion coefficients to alloying elements; expansion coefficient increases slowly with amount of heating until it approaches a maximum. Bibliography.

GRAPHITE FLAKES. The Measurement of Graphite Size in Cast Iron, A. L. Norbury and L. W. Bolton. *Brit. Cast Iron Research Assn.—Bul. (Birmingham)*, no. 26, Oct. 1929, pp. 189-191, 9 figs.

Desirability of defining graphite size more accurately; difficulty of accurately measuring lengths of graphite flakes; photomicrographs of different sizes of graphite structures; variations in length of flakes in given casting.

GRAPHITIZATION. Influence of Finesness of Structure on Annealing of Gray Cast Iron (Influence de la finesse de structure lors du recuit des fontes grises), A. Portevin and P. Chévenard. *Académie des Sciences—Comptes Rendus, (Paris)*, vol. 189, no. 19, Nov. 4, 1929, pp. 759-681, 2 figs.

Two long cylinders were cast simultaneously from four samples of cast iron and annealed by cooling at various temperatures; graphitization in 30-mm. bars takes place much more quickly than in 100-mm. bars; conclusions explain more extensive graphitization of external portions of casting, and variation in hardness of fractured surface.

The Condition and Effects of Graphite in Cast Iron, H. R. Pitt. *Foundry Trade J. (Lond.)*, vol. 41, no. 691, Nov. 14, 1929, pp. 351-352, and (discussion) 352.

Physical properties and aspects of graphite; mechanism of graphite formation; graphitization of non-carbon alloys.

GROWTH. Status of Present Research with Regard to Growth of Cast Iron (Das

Wachsen von Gusseisen nach dem Stande der bisher vorliegenden Forschungsergebnisse), P. Bardenheuer. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 3, Jan. 16, 1930, pp. 71-76.

Phenomena of growth, i. e., distintegration of iron carbide, and oxidation of constituents, are discussed; influence of properties of materials, such as structure and chemical composition, on growth.

Growth of Cast Iron (Das Wachsen des Eisens), W. Schreck. *Giesserei Zeitung (Berlin)*, vol. 27, no. 1, Jan. 1, 1930, pp. 1-3, 9 figs.

Investigations up to present time have shown that growth is greatly increased after passing critical temperature zone of 750 deg. cent. with ordinary iron; not only does growth occur but expansion of iron begins at considerably lower temperatures, and with heating at 400 deg., cast iron, when quenched, does not return to its original state.

HIGH TEST. The Place of the Iron Casting in Industry. *Engineering (Lond.)*, vol. 128, no. 3335, Dec. 13, 1929, pp. 776-777.

Comment on advances made during recent years in improvement of cast iron; decrease in growth and increase in fatigue strength of alloy cast iron; benefits of researches being carried on by British Cast Iron Research Assn. and others.

NICKEL. Nickel Cast Iron in Theory and practice (Nickelgusseisen in Theorie und Praxis), M. Waehlert. *Giesserei (Duesseldorf)*, vol. 17, no. 3, Jan. 17, 1930, pp. 57-63, 15 figs.

Efforts which have been made to improve cast iron are discussed; influence of alloy additions; nickel and nickel chromium; reciprocal effects of these and silicon, phosphorus, and sulphur; raw materials and alloying processes; applications and initial costs.

NICKEL CONTENT. Nickel in the Iron Foundry, A. B. Everest. *Foundry Trade JI. (Lond.)*, vol. 42, nos. 698 and 699, Jan. 2 and 9, 1930, pp. 8-11 and (discussion) 11-12 and 27-28, 12 figs.

Jan. 2: General effects of nickel on cast iron; effects of silicon and nickel on chill and hardness; hardness of nickel and ordinary irons; addition of nickel; practical results from use of nickel; separately cast test bars; American locomotive-cylinder practice; effect of nickel on foundry qualities of iron; elimination of porosity; gasoline-pump castings; cylinder heads. Jan. 9: Nickel additions. Paper presented before Inst. Brit. Foundrymen.

TEMPERATURE EFFECT. Influence of Structure of Cast Iron on Changes Due to High Temperature (Influence de la structure de la fonte sur les alterations subies aux temperatures elevees), A. Le Thomas. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 189, no. 17, Oct. 21, 1929, pp. 639-641.

Differences in behavior of series of 10 bars of cast iron of diameters varying from 13.0 to 100.5 mm., but otherwise similar, due to heat treatment have been examined; more slowly cooling thick bar is more stable than quicker cooling thin one.

CAST IRON ANALYSIS

Notes on the Routine Analysis of Cast Irons and Iron Foundry Raw Materials, A. Smith. *Foundry Trade JI. (Lond.)*, vol. 41, no. 691, Nov. 14, 1929, pp. 357-358 and 360, 1 fig.

Carbon in cast iron; difficulties in sampling; estimation of total-carbon; outline of method; absorption apparatus and absorption agents; Stroehlein apparatus for determination of carbon-content in iron and steel; estimation of graphitic-carbon; combined carbon in gray cast irons; estimation of carbon in ferro-alloys.

CAST IRON ANNEALING

Modern Methods of Annealing Gray and Malleable Cast Iron (Neuzeitliches Gluehen von Grau und Temperguss), R. Stotz. *Giesserei (Duesseldorf)*, vol. 16, no. 52, Dec. 27, 1929, pp. 1209-1220, 21 figs.

Notes on annealing pots of iron alloys resistant to piping; annealing media and their preparation; chamber and tunnel ovens for pulverized-coal and gas firing; pulverizing costs for bituminous coal; ideal annealing curves are presented.

CAST IRON PROPERTIES

Gray Iron Possesses Valuable Engineering Properties. *Foundry*, vol. 58, no. 3, Feb. 1, 1930, pp. 94-97, 17 figs.

Many considerations involved in selection and application of gray iron castings are discussed; gray iron is not one metal, but is a series of alloys of widely varying physical properties; necessity for selection of proper grades is obvious; ductility not needed; hard spots can be eliminated.

Modern Cast Irons and Their Properties, J. G. Pearce. *Mech. World (Manchester)*, vol. 86, nos. 2237 and 2238 Nov. 15 and 22, 1929, pp. 464-465 and 480-482, 7 figs.

Nov. 15: Feature of specification of British Engineering Standards Assn.; relation between size and strength in cast iron. Nov. 22: Fatigue strength; wear resistance; relation of composition to properties.

New Theories of the Mechanical Properties of Cast Iron (Neuere Anschauungen ueber die mechanischen Eigenschaften des Gusseisens), A. Thum. *Giesserei (Duesseldorf)*, vol. 16, no. 50, Dec. 13, 1929, pp. 1164-1173 and (discussion) 1173-1174.

Notch effect of graphite veins and its influence on strength and elasticity of cast iron; evaluation of coefficients of deflection in bending test; ductility and durability; comparison of cast iron and steel.

CAST IRON TESTING

Tests for Cast Iron, J. G. Pearce. *Foundry Trade JI. (Lond.)*, vol. 41, no. 692, Nov. 21, 1929, p. 367.

Question of tests of cast iron as guarantee of quality is discussed; practical test which is easy to make in foundry must take form of chill and break test; question of standard chill test very difficult to solve; fracture in cast iron very valuable piece of information to foundrymen; chemical test.

CHEMICAL EQUIPMENT

METALS. "Double" Metal as a Construction Material for Apparatus (Double als Werkstoff fuer den Apparatebau), G. Durst.

Chemiker-Zeitung (Koethen), vol. 53, no. 87, Oct. 30, 1929, pp. 837-838.

For construction of large vessels with acid-resisting inner surface double metal, consisting of silver or 18-carat gold on backing of copper or bronze, provides material having long life.

CHROMIUM PLATING

HEAT STORAGE. Thermal Storage. *Elec. Times (Lond.)*, vol. 77, no. 1994, Jan. 9, 1930, p. 87.

At Skinnerburn works of Northern Chromium Co. there is total of 24 large tanks, which have to be maintained at temperatures varying between 70 and 140 deg. Fahr.; tanks include chromium-plating, sawdust, hot water and degreasing tanks and various acid baths used for copper, nickel, and aluminum plating; each tank is fitted with heating coil made of steel or lead, depending on nature of electrolyte, and this coil is connected through valves to hot-water mains.

COPPER ALLOYS

Some Elementary Notes on Brasses and Bronzes, H. C. Dews. *Metal Industry (Lond.)*, vol. 35, no. 23, Dec. 6, 1929, p. 539; see also *Foundry Trade J.*, vol. 41, no. 694, Dec. 5, 1929, p. 402.

Composition of brass and copper is discussed with their properties; five per cent tin bronze is used for hot working and is made into strip, wire, sheets, rod, and instrument parts; 10 per cent tin bronze used for casting Admiralty gun metal; 25 per cent tin bronze used for bells and whistles. Abstract of paper presented before Inst. Brit. Foundrymen.

COPPER-SILVER ALLOYS

X-RAY ANALYSIS. X-Ray Determination of Limits of Mixed-Crystal Formation of Silver Copper Alloys (Ueber die roentgenographische Bestimmung der Grenzen der Mischkristallbildung von Silber-Kupferlegierungen) O. Weinbaum. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 12, Dec. 1929, pp. 397-405, 10 figs.

Account of results of analysis made according to X-ray method; preparation of samples; density and strength determination; homogeneity.

COPPER-ZINC ALLOYS

DEZINCING. Processes of Surface Dezincing of Brass and Tombak (Ueber einige Verfahren zur zur Oberflaechenentzinkung von Messing und Tombak), E. Beutel and A. Kutzelnigg. *Zeit. fuer Metallkunde (Berlin)*, vol. 21, no. 12, Dec. 1929, pp. 412-413.

Some new methods are described by use of which it is easy to copper plate zinc-copper alloys without use of electric current; one of these processes consists in annealing tombak, then pickling it in diluted sulphuric acid; three other processes are based on principle that surface of alloy is converted to copper chloride by means of iron chloride, this being reduced by different means to copper; different known methods are discussed.

DURALUMIN CORROSION

Change in Mechanical Properties of Duralumin Sheets Due to Corrosion by Seawater

(Sur l'altération des propriétés mécaniques des toles de duralumin après corrosion par l'eau de mer), E. Herzog and G. Chaudron. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 189, no. 24, Dec. 9, 1929, pp. 1087-1089.

Analysis of results on sheets of various thicknesses which had been exposed for one month to influence of seawater contents in atmosphere.

DURALUMIN WELDING

How to Weld Duralumin. *Aero Digest*, vol. 15, no. 6, Dec. 1929, p. 164.

Precautions to be observed in preparing and welding duralumin are discussed; properties of duralumin; sheet duralumin should be spaced $\frac{1}{4}$ in. per ft. of seam; tensile strength which can be expected of welds made in duralumin varies with methods used in heat treating and quenching.

ELECTRIC FURNACES

Recent Developments in Electric Furnaces, D. F. Campbell. *Inst. of Metals—Advance Paper*, 1929, 20 pp., 8 figs.

Improvements and modifications in melting practice during last two years; relative performance of small and large induction furnaces; high-frequency furnaces; heat-treatment furnaces; specific furnaces, including continuous furnaces for annealing brass strip; largest brass works, where electricity is utilized more than elsewhere described with explanation of uses of electricity, energy consumed, and effect of special precautions to improve power and load factors.

HEAT TREATING. Electric Heating Furnaces, A. H. Vaughan. *Iron Age*, vol. 125, no. 5, Jan. 30, 1930, pp. 357-361, 6 figs.

Much technical data necessary in design of electric heat-treating furnaces; types now in use for steel and non-ferrous products; problems of their design; large tonnages and products handled; advantages of continuous furnace; very large furnaces possible; counterflow units produce good results; electricity only solution for heat treatment of strong aluminum alloys. Paper presented before Am. Soc. for Steel Treating.

MELTING. Metal Melting by Electricity, D. F. Campbell and W. F. Gifford. *Metal Industry (Lond.)*, vol. 35, nos. 25 and 26, Dec. 20 and 27, 1929, pp. 585-587 and 613-614, 4 figs.; see also *Foundry Trade J.*, vol. 41, nos. 697 and 799, Dec. 26 and Jan. 9, 1930, pp. 453-455 and (discussion) 29-30.

Dec. 20: Description of different types of electric furnaces which have been developed for various metal-melting operations; arc furnaces; indirect arc-type electric furnaces for melting brass; iron-core induction furnace; high frequency; operating costs.

Dec. 27: Melting of aluminum by electricity. Abstract of paper read before Inst. of Metals.

METALLURGICAL. Report of the Electric Heat Committee of the Association of Iron and Steel Electrical Engineers for the Year 1928-29, G. H. Schaeffer. *Iron and Steel Engr.*, vol. 6, no. 10, Oct. 1929, pp. 533-540, 15 figs.

Electromagnetic Hevi-Duty hardening furnaces; Homo circulating-air electric

tempering furnaces; carburizing and normalizing; Pull-Thru type furnaces; pit-type electric furnace; rotary-hearth; furnace; automatic dumping; pusher-type furnaces; car-type furnace; electric steel-melting furnace; high frequency furnace for foundry.

STEEL MAKING. Electric Furnaces For Steel Melting, N. R. Davis and C. R. Burch. *Mech. World (Manchester)*, vol. 86, nos. 2242 and 2243, Dec. 20 and 27, 1929, pp. 589-590 and 611-612, 2 figs.; see also *Foundry Trade J. (Lond.)*, vol. 41, no. 696; Dec. 19, 1929, pp. 437-438, 1 fig.

Dec. 20: Classification of electric furnaces for steel melting; four types of furnaces are compared; quality of steels produced in various ways; induction furnace. Dec. 27: Further discussion of induction furnaces is given with reference to furnaces produced by authors. Abstract of paper presented before Manchester Assn. of Engrs.

EXTENSOMETERS

The Huggenberger Tensometer. *Engineer (Lond.)*, vol. 149, no. 3863, Jan. 24, 1930, p. 104, 3 figs.

Tensometer made by A. Huggenberger of Zurich is lever-type extensometer of small size, possessing, it is claimed, high degree of precision and sensitiveness and capable of being fixed rapidly in position.

FORGE SHOP PRACTICE

Surplus Material in the Forging Process (Die materialzugaben im Schmiedewesen). W. E. Makarowitsch. *Werkstattstechnik (Berlin)*, vol. 23, no. 23, Dec. 1, 1929, pp. 666-674, 22 figs.

Rules are given to determine surplus material needed to take care of shrinkage in forging process; formulas are derived and tables are given for surplus materials needed for different kind of forgings.

FOUNDRY PRACTICE

X-RAY ANALYSIS. X-Ray Analysis Applied to Detection of Defects in Foundry Practice (Roentgenologische Erkennungsmoeglich von Guss erzeugungsfehlern in Giessereibetrieben). H. Reininger. *Giesserei (Duesseldorf)*, vol. 17, nos. 2 and 3, Jan. 10, 1930, pp. 40-47 and Jan. 17, pp. 63-71, 50 figs.

Advantage of X-ray analysis in foundry practice are set forth; attempt should be made to apply X-ray diascopy not only to castings, but also to certain cores and molds.

FUELS

Physics in Relation to the Utilization of Fuel, C. H. Lander. *Gas J. (Lond.)*, vol. 188, no. 3475, Dec. 25, 1929, p. 825.

Discussion of value of study of physical structure of fuels in solving fuel problems; use of microscope; application of X-ray to examinations of coal ash; physics of furnace. Abstract of Lecture before Inst. of Physics.

FURNACES, FOUNDRY

GAS-FIRED. Gas-Fired Foundry Furnaces (Ofen fuer Gasfeuerung in der Giesserei). H. Kalpers. *Giesserei (Duesseldorf)*, vol. 17, no. 4, Jan. 24, 1930, pp. 84-91, 19 figs.

Advantages of gas firing in foundries are set forth; melting, annealing, and enameling furnaces; enameling and drying ovens; other uses of gas firing.

FURNACES, HEAT TREATING

Furnace Improvement Is Greatest Need in Heat Treatment. *Iron Trade Rev.*, vol. 86, no. 1, Jan. 2, 1930, pp. 28-29, 2 figs.

Various developments in heat treatment during 1929 are discussed.

Furnaces and Equipment. *Am. Mach.*, vol. 72, no. 3, Jan. 16, 1930, pp. 125-126, 9 figs.

Semi-annual résumé of heat-treating furnaces described in Shop Equipment News sections of magazine during last six months of 1929, is given.

AUTOMATIC CONTROL. New Hardening and Annealing Automatic Oven with Material Feed (Ein neuer Haerte und Anlassautomat mit Materialzufuehrung). O. Lich. *Werkstattstechnik (Berlin)*, vol. 23, no. 23, Dec. 1, 1929, pp. 676-678, 7 figs.

Description of new tempering and annealing oven that automatically feeds material and carries it through oven.

FUELS. The Application of Correct Gas-Flow Principles in Furnaces, E. J. Plumley. *Iron and Coal Trades Rev. (Lond.)*, vol. 120, no. 3229, Jan. 17, 1930, pp. 71-74, 9 figs.

Suggestions for reducing fuel consumption; review of laws governing movement of gases in furnaces; furnaces discussed are of type for reheating and heat treatment, although it is equally important that furnaces of every type should be designed for correct gas flow; open-hearth furnaces purposely avoided because they are usually designed empirically as far as furnace laboratory is concerned. Read before Cleveland Instn. of Engrs.

GAS-FIRED. Gas Furnaces for Carburizing, W. F. Chubb. *Automobile Engr.*, (Lond.), vol. 19, no. 262, Dec. 1929, pp. 496-497, 2 figs.

Recent development in gas-fired furnaces for carburizing cam-shafts, gears, and other automobile components; advantages taken of charging machine slots to provide outlets for exhaust gases; further departure from customary practice lies in construction of lower part of recuperative system.

HARDNESS TESTING

Brinell Indentations with Different Testing Loads (Brinelleindrucke bei verschiedener Pruefplast). P. W. Doehmer. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 1, Jan. 1930, pp. 31-32, 3 figs.

Author claims that for practical testing purposes, conversion of ball-impression diameters obtained with specific load into diameters obtained with other loads is not possible without knowledge of N-value of material; it is simpler to actually measure desired ball impression with other testing loads instead of calculating it; some results of practical calculations are listed.

Conversion of Hardness Numbers of Steels and Some Metals (Umrechnung von Haerteziffern bei Staehlen und einigen Metallen). A. Wallich and H. Schallbroch. *Maschinenbau (Berlin)*, vol. 8, no. 24, Dec. 19, 1929, pp. 824-827, 6 figs.

Conversion values relative to Brinell number are experimentally determined for hardness testing equipment of various types and for carbon and chromium-nickel steels, aluminum and copper alloys; conversion curves are developed for practical use.

HIGH SPEED STEEL

The Tungsten Situation and Its Effect Upon High-Speed Steel Prices. *Machy. (Lond.)*, vol. 35, no. 899, Jan. 2, 1930, p. 456.

Effect of ferrotungsten ore prices on tool steel industry is discussed; reasons for increase in price and outlook for future; key to situation seems to lie in China; when it is known through what channels regular supplies can be obtained from that country, clearer view of situation should be obtainable.

IRON

HANDBOOK. Gmelins Handbuch der anorganischen Chemie—Eisen. 8th Edition, published by Deutsche Chemische Gesellschaft, Berlin, Verlag Chemie G.m.b.H., parts A, no. 2, 1050 r.m.; part B, no. 1, 36 r.m.

Part A covers physical properties of pure iron. Part B deals with iron compounds; mechanical and physical properties, adsorption and radiation; electric and magnetic properties, chemical behavior, etc.

IRON ALLOYS

ANALYSIS. Oxygen Determination in Iron Alloys According to Hydrogen Reduction Process. (Ein Beitrag zur Frage der Sauerstoffbestimmung in Eisenlegierungen nach dem Wasserstoff-Reduktionsverfahren), H. Petersen. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 7, Jan. 1930, pp. 459-468, 4 figs.

Possibilities of carbon-monoxide determination; critical discussion of hydrogen process; results of authors experiments. 3 page-Bibliography.

Determination of Specific Volume of Iron, Nickel, and Iron Alloys in Molten State (Bestimmung des spezifischen Volumens von Eisen, Nickel und Eisenlegierungen im geschmolzenen Zustand), N. Ericson and G. Ericson. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 7, Jan. 1930, pp. 473-486, 14 figs.

Review of earlier studies; description of experimental equipment and production of magnesia vessels; possible sources of error; study of iron-carbon and iron-nickel alloys; further studies of iron alloyed with manganese, chromium, tungsten, aluminum, silicon and phosphorus.

TERNARY. Sulphur-Iron-Carbon System Beitrag zur Kenntnis des Systems Schwefel-Eisen-Kohlenstoff, H. Hanemann and A. Schildkoetter. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 2, Jan. 9, 1930, pp. 42-43, 2 figs.

Review of literature; determination of concentration and solidification temperature of ternary eutectoid; solidification phenomena in most important fields of ternary diagram for iron-iron carbide-iron sulphide system; method is described of determining carbon in presence of large quantities of sulphur.

IRON AND STEEL

Irons, Steels, and Alloys. *Am. Mach.*, vol. 72, no. 3, Jan. 16, 1930, pp. 139-140.

Semi-annual résumé of irons, steels and alloys described in Shop Equipment News sections of magazine during last six months of 1929, is given, including different types of iron, chrome iron, alloys, heat and abrasive-resistant iron, acid-resistant alloys, die and tool steels, and screw stocks.

ALUMINUM COATINGS. Servarizing. *Metal Industry (Lond.)*, vol. 35, no. 24, Dec. 13, 1929, p. 571.

Servarizing process for treating introduced commercial iron and steels to render them less liable to destruction under high-temperature requirements and to preserve mechanical properties; part treatment in aqueous solution and part in molten electrolyte, resulting in application of unbroken envelope of alumina which, alloying with foundation metal, forms close and highly refractory surface layer non-scaling and resistant to penetration by destructive gases; applications steam generators and gas furnaces.

CARBON CONTENT. Volumetric Determination of Carbon in Iron and Steel Alloys of Low Combustibility (Zur volumetrischen Kohlenstoff-Bestimmung in schwer brennbaren Eisen- und Stahllegierungen), E. Zindel. *Chemiker Zeitung (Koethen)*, vol. 53, no. 92, Nov. 16, 1929, pp. 891.

As catalyst in combustion of ferro-alloys and complex alloy steels, addition of soft iron or mild steel turnings of known carbon content is recommended in place of bismuth oxide; complete combustion of all carbon is effected in short time at temperature required for plain carbon steel and there is no action on walls of tubes such as is obtained when using bismuth oxide.

IRON AND STEEL METALLOGRAPHY

The Solidification of Cast Irons and Quenched Steels, A. L. Norbury. *Fuels and Furnaces*, vol. 8, no. 1, Jan. 1930, pp. 93-100, 15 figs.

Constitutional diagrams for cast irons containing 0, 2 and 4 per cent of silicon and for quenched steels were constructed and were used in explaining widely different microstructures, combined carbon contents, tendencies to chill and mechanical properties obtained in gray cast irons having identical compositions and cast under identical conditions. Abstract of paper read before Iron and Steel Inst.

IRON AND STEEL RESEARCH

Progress in Metallurgical Research, H. C. H. Carpenter. *Iron and Coal Trades Rev. (Lond.)*, vol. 120, no. 3230, Jan. 24, 1930, pp. 152-153.

Most important event of year 1929 is formation of Iron and Steel Industrial Research Council composed of members of Iron and Steel Institute, National Federation of Iron and Steel Manufacturers, and of research associations of industries connected with iron and steel; policy is encouragement of definitely technical investigations designed to overcome immediate and pressing difficulties, and to explore most obvious lines of development by suitable means; research in United States; other researches.

MACHINE TOOLS

ALUMINUM. Aluminum in Heavy Machinery. *Am. Mach.*, vol. 71, no. 24, Dec. 12, 1929, pp. 959-960, 2 figs.

Discussion of what three important machine-tool builders are doing to reduce weight in their products; effects on costs, weight, and design, of use of aluminum and light alloys in heavy machine tools.

MANGANESE BRONZE

LEAD CONTENT. The Effect of Lead on Manganese Bronze. J. Silberstein. *Metal Industry (Lond.)*, vol. 35, no. 26, Dec. 27, 1929, p. 618, 2 figs.

Composition and properties of manganese bronze are discussed; results of investigations on influence of lead on brass briefly covered.

MANGANESE STEEL

Effect of Manganese on Distribution of Carbon in Steel. B. M. Larsen. *U. S. Bureau of Mines—Tech. Paper*, no. 466, 1929, 31 pp., 26 figs.

Dendritic segregation of manganese; arrangement of dendrites and sorbite-ferrite grains; structures related to effect of manganese on critical point of iron; removal of manganese segregation by diffusion at high temperatures; etching effects of copper chloride reagent; carbide structures with increasing manganese; rate of cooling and carbon segregation; banded structures in rolled or forged bars; effect of manganese on eutectoid point of carbon steel; stability of carbides. Bibliography.

Manganese in Simple Steels. H. D. Hibbard. *Fuels and Furnaces*, vol. 8, no. 1, Jan. 1930, pp. 51-54.

General rules in steel making; article deals chiefly with open-hearth steels; manganese cure for red-shortness; early steels.

Manganese in Simple Steels. H. D. Hibbard. *Fuels and Furnaces*, vol. 8, no. 2, Feb. 1930, pp. 217-219.

Author continues discussion covering manganese in charge materials, and part played by manganese in working charge.

Studies of Hadfield's Manganese Steel with the High-Power Microscope. J. H. Hall. *Am. Inst. Min. and Met. Engrs.—Trans.*, 1929, pp. 382-427, 57 figs.

Nature of deformation lines in crystals of manganese steel, which was subject actively in Howe's mind during closing years of his life, is discussed; deformation lines contain martensite; discovery of heat treatment for grain refinement; new structure found in austenite. Abstract of Howe Memorial lecture presented before Am. Inst. Min. and Met. Engrs.

MANGANESE STEEL MANUFACTURE

Electric-Furnace High-Content Manganese Steel (L'acier à forte teneur de manganèse au four électrique). *Jl. du Four Electrique (Paris)*, vol. 38, no. 8, Aug. 1929, pp. 269-270.

Details of preparation of manganese steel by adding ferromanganese directly to ordinary steel as soon as charge is fused and alloying under initial slag.

MATERIALS TESTING

ELONGATION. Apparatus for De-

termination of Thermal Elongation of Solid Bodies at High Temperatures (Ueber einen Apparat zur Bestimmung der thermischen Ausdehnung fester Koerper bei hohen Temperaturen). H. Gerdien and W. Jubitz. *Zeit. fuer Technische Physik (Leipzig)*, vol. 10, no. 12, 1929, pp. 614-620, 7 figs.

Measuring methods and apparatus; discussion of sources of error; thermal elongation of silver, nickel, mass of Pythagoras white and iron are given as examples.

METALLOGRAPHY

Atlas Metallographicus, by Hanemann and Schrader. *Gebrueder Borntraeger, Berlin*, in 2 issues, no. 6 charts 41-48, and no. 7, charts 49-56.

These two issues in pamphlet form, nos. 6 and 7, are part of work giving reproductions of microstructures of all known industrial metals and alloys.

X-RAYS. X-ray Metallography (La métallographie par les rayons X), Mathieu. *Génie Civil (Paris)*, vol. 96, no. 1, Jan. 4, 1930, pp. 1-9, 38 figs. partly on supp. plate.

General principles of X-ray metallography methods and technique; including description of special French and German apparatus used in this work; critical review of methods proposed by Clark in his book "Applied X-rays."

METALLURGY

The Broad View. *Metallurgist (Supp. to Engineer, Lond.)*, Jan. 31, 1930, p. 2.

It is claimed that existing demarcation between ferrous and non-ferrous metallurgy is fundamentally unsound and undesirable; but field of ferrous or non-ferrous metallurgy is so extensive that no one can cover whole of either, and still less of both; practical question arises how dangers and evils of excessive specialization are to be met; joint meetings and discussions bringing together those who deal with same material or same subject from widely different points of view.

PHOTOELECTRIC SEPARATION

Photo-Electric Metallurgy. R. W. Drier. *Indus. and Eng. Chem.*, vol. 22, no. 2, Feb. 1930, pp. 153-157, 4 figs.

New method of separating minerals, metals, and metallurgical products, on basis of color and luster is described; method utilizes bead of light and photoelectric cell actuated by light reflected from particles of material, and separation is based on differences in reflective indices of materials; other suggestions for study in developing sensitivity of process are outlined.

METAL SPRAYING

Protection of Iron and Steel by Metal Spraying. *World Power (Lond.)*, vol. 13, no. 53, Jan. 1930, pp. 65-66, 1 fig.

Metallization of iron and steel consists of spraying with aluminum or similar coating with view to protection from attack by oxygen at rather high temperatures; metal-coating method; cast iron at high temperatures.

METALS

CORROSION RESISTANT. Theory and Practice of Corrosion Resistant Equipment. A. Portevin. *Iron Age*, vol. 125, no. 4, Jan. 23, 1930, p. 306.

Choice of non-corrosive substances from price and property point of view; chromium

steels. Abstract of paper presented before Conservatoire des Arts et Metiers, Paris, France.

CRYSTALLIZATION. Theory of Recrystallization. (Zur Theorie der Rekristallisation). G. Tammann. *Zeit. fuer anorganische und allgemeine Chemie (Leipzig)*, vol. 185, nos. 1 and 2, Dec. 10, 1929, pp. 1-34, 5 figs.

General physical theory of recrystallization of metals; state of crystal after its plastic deformation; formation of recrystallization nuclei; changes in texture and structure accompanying recrystallization, with special reference to changes in grain size during thermal deformation.

DEFORMATION. Dynamische und Statische Zugversuche an Aluminium-Einzelkristallen. J. Weerts. (Forschungsarbeiten, heft 323). Berlin V. D. I. Verlag, 1929, 20 pp., illus., diagrs. 4-r.m.; see also abstract in *V. D. I. Zeit. (Berlin)*, vol. 74, no. 1, Jan. 4, 1930; pp. 21-22, 1 fig.

Investigation of reasons for observed effect of speed of deformation of ductile metals upon their resistance to deformation; author investigated behavior of large aluminum crystals when subjected to various tests of their tensile strength; new light was obtained upon phenomena of crystal deformation and resistance. Eng. Soc. Lib., N. Y.

FATIGUE. Fatigue Testing of Construction Materials (Dauerversuche an Werkstoffen). P. Ludwik. *V. D. I. Zeit. (Berlin)*, vol. 73, no. 51, Dec. 21, 1929, pp. 1801-1810, 17 figs.

Summary of recent research on fatigue testing with constant and variable loads; flow of solids; reversal of stresses; internal stresses, hysteresis, etc.; fatigue failure; short methods of fatigue testing; relation between vibration resistance and other properties; effect of nature of surface, notches and heat treatment; impact fatigue testing.

PROPERTIES. Metall und Legierungskunde. M. Schwarz. 2d edition. Stuttgart, Ferdinand Enke, 1929. 383 pp., illus., diagrs., tables, 26-r.m.

Revised and enlarged reprint of article on metals and alloys in Dammmer's *Chemische Technologie der Neuzeit* is remarkably full, compact description of these substances; valuable feature is alphabetical list of 300 common alloys with their compositions; exceedingly valuable work of reference. Eng. Soc. Lib., N. Y.

The Relation Between the Properties of Engineering Materials and Their Ultimate Structures. G. W. Todd. *North-East Coast Instn. of Engrs. and Shipbldrs.—Trans. (Lond.)*, vol. 45, 1928-1929, pp. 243-258 and (discussion) 258-260, 6 figs.

Atomistic doctrine of matter; relations between specific heats and coefficients of expansion; quantum theory leads to expressions from which specific heat of solid can be obtained in terms of its absolute temperature and characteristic frequencies of vibration of its atoms; evidence of X-ray analysis; electrical theory of crystal lattice; mechanism of deformation; observation on alloys.

X-RAY ANALYSIS. Roentgenographie der Metalle und ihrer Legierungen. M. C. Neuburger. Stuttgart, Ferdinand Enke, 1929. (Sammlung chemischer und chemisch-tech-

nischer Vortraege, n. f. heft 1). 278 pp., illus., diagrs., tables, 25 r.m.

Data on structure of metals and alloys which various investigators have obtained by using X-rays are here summarized and presented systematically; 59 systems and 20 metals are included; lengthy bibliography given. Eng. Soc. Lib., N. Y.

METALS ANALYSIS

Select Methods of Metallurgical Analysis. W. A. Naish and J. E. Clennell. N. Y. John Wiley and Sons, 1930, 495 pp., illus., tables, \$7.50.

Compendium by two experienced chemists, of methods of qualitative and quantitative analysis which they have found most rapid, accurate and practical for metallurgical work; special features are attention paid to rare elements and extensive references to standard works and original papers; directions are concise and clear; in addition to general methods for elements, methods are given for usual commercial metals, alloys, ores, slags and refractories. Eng. Soc. Lib., N. Y.

ELECTROLYTIC. Analyse des Métaux par Electrolyse. A. Hollard and L. Bertiaux, 4th edition. Paris, Dunod, 1930, 232 pp., diagrs. 62, 50 fr.

In addition to giving detailed descriptions of methods and apparatus for analyzing metals, alloys, and commercial products, this manual sets forth general principles, studies general methods of electrolytic separation and deposition of metals and discusses electric generators; although primarily devoted to electrolytic methods, other methods of analysis are described in cases where they are better. Eng. Soc. Lib., N. Y.

X-RAY. Results of Crystallographic Analysis by X-Rays (Sur quelques résultats d'essais cristallographiques par rayons X) A. Roux and J. Cournot. *Revue de Métallurgie (Paris)*, vol. 26, no. 12, Dec. 1929, pp. 655-661, 6 figs.

Structure of simultaneous electrolytic depositions of two metals is studied in this issue which is first of series dealing with five different problems of crystallography. (To be continued.)

METALS CORROSION

Die Korrosion. Bd. 1; Allgemeiner und theoretischer Teil. O. Kroehnke and W. Beck. Leipzig, S. Hirzel, 1929, 208 pp., illus., tables, 16-r.m.

First volume of elaborate monograph on corrosion and protection which will give special attention to extensive German literature on those subjects; present section is devoted to general and theoretical principles; corrosion is discussed from point of view of physical chemistry, and its phenomena are traced to basic principles; Bibliography. Eng. Soc. Lib., N. Y.

Corrosion of Metals and Alloys (La corrosion des métaux et alliages). A. Portevin. *Revue de Métallurgie (Paris)*, vol. 26, nos. 11 and 12, Nov. 1929, pp. 606-631 and Dec., pp. 635-654, 42 figs.

Nov.: Effects due to corrosion and various modes of deterioration are discussed; principal factors which influence corrosion; discussion includes ferrous and non-ferrous metals. Dec.: Methods of evaluating and

characterizing corrosion; heat of dissolution and reaction; methods of testing corrosion; so-called inoxidizable steels; conclusions.

METALS TESTING

ELONGATION. Significance and Evaluation of Elongation of Metals (Zur Deutung und Bewertung der Bruchdehnung bei Metallen), W. Kuntze. *Zeit. fuer Metallkunde (Berlin)*, vol. 22, no. 1, Jan. 1930, pp. 14-22, 17 figs.

It is claimed that maximum elongation is not proof of resistance to rupture; results of tests in which influence of elongation under bending and torsion, and its relation to **strain hardening** and decay of material relations between elongation and notch toughness, etc., are determined.

TOUGHNESS. Importance of Toughness for the Designer (Die Bedeutung der Zuehigkeit fuer den Konstrukteur), H. Edert. *Maschinen-Konstrukteur (Berlin)*, vol. 62, no. 23, Dec. 1, 1929, pp. 533-537, 11 figs.

Importance of testing construction materials is emphasized; bending and tension tests of steel are illustrated by examples.

WEAR. Recent Results of Research on Wear of Materials (Neuere Ergebnisse der Abnutzungsforschung), M. Fink. *V. D. I. Zeit. (Berlin)*, vol. 74, no. 3, Jan. 18, 1930, pp. 85-87, 4 figs.

Features of Amsler wear-testing machines; results of recent research in Germany, Great Britain, and United States on such subjects as rusting of steel, mechanical production of oxidation in rolling, rail corrugations, etc.

YOUNG'S MODULUS. Young's Modulus Determined with Small Stresses, D. K. Froman. *Phys. Rev.*, vol. 35, no. 3, Feb. 1, 1930, pp. 264-268, 2 figs.

Report from Ryerson Physical Laboratory, of University of Chicago on interferometer method of determining extensions of metallic rods of brass, steel, copper, aluminum, and nickel under stresses considerably less than those used in commercial testing; Young's modulus was found to increase very rapidly as stress increased from zero, reach maximum at comparatively small stress, and then to decrease almost exponentially to ordinary value.

NICKEL

Nickel in 1929. *Min. and Met.*, vol. 11, no. 277, Jan. 1930, pp. 8-9.

Increase in nickel consumption; uses of nickel steel; corrosion resistance of nickel alloys; increase in use and applications of monel metal.

NICKEL ALLOYS

Nickel Alloys (Nickel in Nichteisen-Metallen). *Zeit. fuer die Gesamte Giessereipraxis (Berlin)*, vol. 50, nos. 51 and 52, Dec. 22, 1929, pp. 209-210 and Dec. 29, 1929, pp. 213-214.

Discussion of most important nickel alloys, including nickel brasses and bronzes, and nickel-copper alloys; nickel in light metals.

OPEN-HEARTH FURNACE PRACTICE

Open-Hearth Trends during 1929, L. F. Reinartz. *Blast Furnace and Steel Plant*, vol. 18, no. 1, Jan. 1930, pp. 96-99.

Progress accomplished in furnace construction towards larger capacities and toward fuel conservation and in application of modern research mark present situation; furnace construction is being improved; small shop demonstrates value of insulation; improvement of refractories is slow; open-hearth man is aided by research.

BASIC. Progress in Basic Open-Hearth Practice, O. H. Steel. *Furnaces and Steel Plant*, vol. 18, no. 1, Jan. 1930, pp. 114-115.

Quality steel is produced under quantity conditions through better operating practice; furnace capacities increased; steel a by-product of slag, good slag results in good steel; deoxidizers; cleaners; effect of untoward circumstances nullified.

PIPE, CAST IRON

CORROSION. How to Avoid Loss by Pipe Corrosion, J. R. Baylis. *Water Works Eng.*, vol. 83, no. 1, Jan. 1, 1930, pp. 13-14, 31-32 and 35-36, 4 figs.

Controlling factors of corrosion in its various forms; theory of corrosion quantities of hydrogen gas liberated by corroding iron and zinc at 100 deg. cent.; no coating gives permanent protection in corrosive water; treatment to prevent corrosion; solubility equilibrium of calcium and magnesium carbonates; how to treat variable-character waters for corrosion. Paper read before Water Works Assn.

RAILROAD MATERIALS

VANADIUM STEEL. Vanadium Steels Used for Railroad Equipment, G. L. Norris. *Iron Age*, vol. 125, no. 4, Jan. 23, 1930, p. 297.

Uses of vanadium steel for locomotive forgings and castings; properties of vanadium steel; reasons for troubles encountered by railroad men with quenched and tempered forgings.

ROLLS, CHILLED

HARDNESS. Scleroscope Hardness of Chilled Rolls, W. H. Melaney. *Blast Furnace and Steel Plant*, vol. 18, no. 1, Jan. 1930, pp. 100-101.

Measure of surface hardness gives imperfect idea of value of roll in service for which it was made; mills have different practice; heat is most destructive element roll has to cope with; hardness of face; scleroscope hardness negligible; physical structure counts most; hardness versus toughness.

SILICON STEEL CASTINGS

Properties of Silicon Steel in Form of Steel Castings (Ueber die Eigenschaften von siliciumlegiertem Stahl in Form von Stahlguss), E. H. Schulz and F. Bonsmann. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 6, Feb. 6, 1930, pp. 161-168, 14 figs.

Investigations of six silicon-steel mixtures in comparison with unalloyed steel castings; strength properties with and without annealing; influence of annealing temperature; tensile and notched-bar tests after different pretreatments at minus 80 to plus 500 degrees Cent.; results of wear and corrosion tests.

DEOXIDATION. Certain Methods of Deoxidizing Steel, J. M. Gaines, Jr. *Blast*

Furnace and Steel Plant, vol. 18, no. 1, Jan. 1930, pp. 102-104, 1 fig.

Deoxidation as usually performed is short cut involving certain sacrifices in steel quality; carbon and iron oxide in iron; limiting conditions; rate of carbon elimination; alternative methods for deoxidation.

SLAG INCLUSIONS. Slag (Solid Non-Metallic) Inclusions in Steel. (Ueber Schlacken bezw. nichtmetallische Einschlüsse im Stahl), C. Benedicks. *Zeit. des Oberschlesischen Berg-u. Huettenmaennischen Vereins zu Katowice (Katowice)*, vol. 68, no. 9, Sept. 1929, pp. 470-474, 3 figs.

Question is based on studies and research; review of studies and theories on how to minimize slag formations. Translated from English.

STEEL ANALYSIS

On the Thermal Analysis of Quenched Carbon Steels, S. Sato. *Tohoku Imperial Univ.—Science Reports (Sendai)*, vol. 18, no. 3, Oct. 1929, pp. 303-316, 11 figs.

Quenched Swedish steels varying in carbon content from 0.202 up to 1.8 per cent were studied by method of differential thermal analysis with very sensitive apparatus, and it was found that during slow heating of quenched steels, evolution of heat is observable in range of temperature of 100 to 170 deg. Fahr.; (In English.)

STEEL CASTINGS

GRAPHITE FLAKES. Origin of Flakes in Steel (Om uppkonsten av innersprickor ("flakes") i stal), C. Benedicks and H. Lofquist. *Jernkontorets Annaler (Stockholm)*, no. 11, 1929, pp. 592-600.

Research adds to previous theories that flakes may originate from expansion during casting and incomplete temperature distribution before forging or rolling; theories are explained and corroborated on test pieces; means for prevention of flakes are recommended. Bibliography.

DEFECTS. Steel Castings and Their Design with Regard to Castings Properties and Machinability (Stahlformgusstuecke und ihre Konstruktion mit Rucksicht auf die Giessbarkeit und die Bearbeitung). *Zeit. fuer die Gesamte Giessereipraxis (Berlin)*, vol. 50, nos. 51 and 52, Dec. 22, 1929, pp. 431-433 and Dec. 29, 1929, pp. 441-443, 11 figs.

Discussion of defects occurring frequently with steel castings, such as piping and cold cracks, and suggestions for their prevention.

STEEL FOUNDRIES

Steel Foundry Centralizes Operations, N. F. Hindle. *Iron Trade Rev.*, vol. 86, no. 3, Jan. 16, 1930, pp. 37-41 and 92, 6 figs.

Description of Farrell-Cheek Steel Foundry Co., Sandusky, Ohio; patterns easily located; pneumatic rammers used; separation of sand; recent enlargement of core-room; pouring practice; heat treatment.

STEEL HEAT TREATMENT

Structural Steel Heat Treated, P. F. Lee and H. A. Schade. *Iron Age*, vol. 125, no. 7, Feb. 13, 1930, pp. 510-514, 1 fig.

Results of investigation undertaken to determine what physical properties could be

obtained by heat treatment of hot rolled low-carbon steel, comparable to S. A. E. 1020 steel; preliminary tests on 45 steels; test pieces given various draws after water-quench; high-elastic-limit steel produced by quenching 0.20 carbon 0.60 manganese steel from 1600 deg. Fahr. and drawing at 1100 deg.; welded joints respond to same treatment; tests on weldability of structural steel.

DEFECTS. The Heat Treatment of Steel, H. Rickli. *Engineering (Lond.)*, vol. 129, no. 3342, Jan. 31, 1930, pp. 141-142.

Editorial comment on paper presented before World Power Conference in Tokyo, in which author drew attention to number of cases in which attempt to improve properties of alloy steels by heat treatment had been responsible for explosion of rotors of high-speed three-phase alternators; it seems certain that immediate cause of accidents was internal stresses set up by heat treatment; he suggests abandonment of process of heat treatment, and use for rotors of well-annealed alloy steels.

STEEL INGOTS

Designing Ingot Molds to Reduce Losses, E. Gathmann. *Blast Furnace and Steel Plant*, vol. 18, no. 1, Jan. 1930, pp. 119-121, 7 figs.; see also *Iron Trade Rev.*, vol. 86, no. 2, Jan. 9, 1930, pp. 25-27, 7 figs.

Review of trend of ingot-mold design is presented with special reference to blooming practice; original type corrugated mold chamber; primary sides of ingot must be relatively narrow and must be in higher plane than corner salients of ingot; later successful modifications of ingot contour.

HETEROGENEITY. Heterogeneity in Steel Ingots and Its Amerioration, W. H. Hatfield. *Iron Age*, vol. 125, no. 5, Jan. 30, 1930, p. 368.

Discussion of formation of aggregation of metallic crystals in steel ingots; characteristics of steel ingots; effects of differential freezing; factors affecting heterogeneity. Abstract of paper presented before South Wales Inst. of Engrs. at Cardiff.

STEEL MANUFACTURE

Steel Metallurgy in 1929, C. H. Herty, Jr. *Blast Furnace and Steel Plant*, vol. 18, no. 1, Jan. 1930, pp. 83-84.

Remarkable developments in iron and steel metallurgy, which have taken place during past few years, are outlined; most outstanding is Aston process for production of wrought iron; alloy-steel production broadens; nitrogen and steel; open-hearth combustion control slag control in open-hearth processes; Bessemer steel under study.

Huette; Taschenbuch fuer Eisenhuettenleute, Herausgegeben vom Akademischen Verein Huette, E. V. in Berlin. 4th edition. Berlin, Wilhelm Ernst and Sohn, 1930. 968 pp., illus., diagrs., tables, 35-r.m.

Steel and iron makers and foundrymen who read German will find this pocket-book decidedly valuable, for it brings together enormous amount of up-to-date information on blast furnace, steel works, and foundry practice, compiled by German specialists in various fields; edition has been thoroughly revised and number of new sections added. Eng. Soc. Lib., N. Y.

RESEARCH. Research Necessary for Plant Control of Manufacture and Subsequent Treatment of High-Quality Steel (Die Betriebsüberwachung bei der Herstellung und Weiterverarbeitung von Edelstahl und die dadurch bedingte Betriebsforschung), R. Hohage. *Stahl und Eisen (Duesseldorf)*, vol. 50, no. 4, Jan. 23, 1930, pp. 93-97 and (discussion) 97-99, 5 figs.

Notes on inspection of raw material; melting and slag handling; temperature measurement; pouring of steel and necessary tests; heat-conductivity determination preceding heat treatment; hardness testing; quenching; methods of determining toughness; defects and their prevention.

Physical Chemistry of Steelmaking—Round Table. *Am. Inst. Min. and Met. Engrs.—Trans.*, 1929, pp. 233-259, 1 fig. See also pp. 260-283.

Influence of silicon content of pig iron on removal of sulphur or phosphorus from steel; causes and correction of foaming; effect of high manganese on sulphur content; form of iron oxide in slag; control of rate of carbon elimination; pressure of carbon monoxide in steel; slag action in ladle; gases given off during solidification. Informal general discussion during meeting in Feb. 1929.

STEEL PLATE, ARMOR

Armor Plate, R. E. Paine. *Army Ordinance*, vol. 10, no. 58, Jan.-Feb. 1930, pp. 239-247, 28 figs.

Possibilities of utilizing low-carbon steels are presented; history of utilization of metals as means of war protection; results of ballistic tests with low-carbon steels. Bibliography.

STEEL TESTING

Testing of Hardened Steel (Provnig av hardat stal), A. Lundgren. *Statens Provvningsanstalt (Stockholm)*, no. 45-46, 1929, pp. 1-9.

Report of research to determine effect of velocity of quenching after tempering and effect of time of tempering on mechanical properties of hardened steel.

TESTING MACHINES

A New Dead-Weight Testing Machine of 100,000 Pounds Capacity, L. B. Tuckerman, H. L. Whittemore, and S. N. Petrenko. *U. S. Bur. Standards—Jl. of Research*, vol. 4 No. 2, Feb. 1930, pp. 261-264, 4 figs. on supp. plates.

Functions of Bureau of Standards; and importance of calibrating testing machines; development of proving ring; need for apparatus for applying, preferably by dead weights, forces which are known accurately; dead-weight machine which has been installed at Bureau; particular attention is given to accuracy of forces which can be applied by this machine and precautions for maintaining accuracy.

TOOL STEEL

Modern Tool Steels, J. A. Hopkinson. *Automobile Engr. (Lond.)*, vol. 19, no. 262, Dec. 1929, pp. 499-500.

Consideration of correct use and applica-

tion of tool steels; standardization of definite analysis to suit specific conditions together with standard heat treatments will be correlated and applied universally; cutting tools made from tungsten carbide; other steels for cutting tools; die steels of great interest at present time.

HEAT TREATMENT. Tempering Cutting Tools, J. T. Towilson. *Am. Mach.*, vol. 72, no. 6, Feb. 6, 1930, p. 248.

Information regarding tempering of steels used for cutting tools.

TUNGSTEN STEEL

ANNEALING. Defects in Tungsten Steels Due to Heat Treatment (Bei der Verarbeitung von Wolframstaehlen entstehende Fehler), W. Wrazei. *Zeit. des Oberschlesischen Berg- u. Huetttenmaennischen Vereins zu Katowice (Katowice)*, vol. 68, no. 11, Nov. 1929, pp. 591-594, 14 figs. on supp. plates.

Results of improper annealing and forging of tungsten steel; varieties of steel that disintegrate; method of annealing and its influence on properties of steel.

VANADIUM

Possibilities of Production of Radium and Vanadium from Carnotite, H. A. Doerner. *Indus. and Engr. Chem.*, vol. 22, no. 2, Feb. 1930, pp. 185-189.

Vanadium from carnotite and related ores; distribution and variation of production costs; production from low-grade ores; concentration methods; extraction of radium from concentrates; extraction with acids; preliminary roasting; chemical dissolution of silica; volatilization of silica; recovery of vanadium and uranium.

WELDS—HEAT TREATMENT

A Contribution to the Study of Influence of Welding Conditions and Subsequent Heat Treatment on the Structure of the Weld, K. Kuettner and V. N. Krivobok. *Am. Welding Soc.—Jl.*, vol. 8, no. 10, Dec. 1929, pp. 40-62, 19 figs.

Report presented to Fundamental Research Committee of American Bureau of Welding is given; in study of resistance welds of low-carbon wire, recrystallization experiments show that gas absorption is much less than in electric arc process and probably less than in oxyacetylene welding. Study of metallurgical literature of welding processes given.

X-RAY ANALYSIS

The Efficiency of Production of Fluorescent X-Rays, A. H. Compton. *Lond., Edinburgh, and Dublin Philosophical Mag. and Jl. of Science (Lond.)*, vol. 8, no. 54, Dec. 1929, pp. 961-977, 3 figs.

For each quantum of energy absorbed by K electrons there should be emitted one quantum of fluorescent X-rays of K type; ratio of absorbed to emitted rays can thus be directly calculated; this simple theory has predicted two important results which are consistent with experiment; intensity of fluorescent X-rays is found not to be as great as theory indicates.

News of the Society

MINUTES OF MEETING OF THE BOARD OF DIRECTORS

HOTEL PENNSYLVANIA, NEW YORK CITY, FEBRUARY 5, 1930—7:30 P. M.

Present

R. G. Guthrie	W. H. Eisenman
J. M. Watson	A. H. d'Arcambal
A. O. Fulton	O. E. Harder

F. T. Sisco

Absent

W. B. Coleman	Zay Jeffries
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Invited Guests

V. O. Homerberg, Chairman, Publication Committee
 H. M. Boylston, Member, Publication Committee
 R. T. Bayless, Editor, TRANSACTIONS
 K. W. Akers, Powers-House Company
 John Anderson, Powers-House Company.

UPON motion properly made, seconded and unanimously carried, the Board approved the changes in the TRANSACTIONS, essentially the ten suggestions, with such minor changes as might be necessary in the course of the development of the publication. They are as follows:

1. That the new publication should contain, in addition to the usual large amount of material on metallurgical subjects, articles and plant write-ups on the following subjects: Forging, non-ferrous materials, manufacture of steel, welding.
2. That technical papers presented at the conventions should be presented in the new publication in extended condensations or rewrites or in full, at the discretion of the editorial staff.
3. That convention papers and discussions should be made available in 6x9 book form for the membership as soon after the close of the convention as possible at a cost of \$2.50 per volume for binding.
4. That an item covering the cost of binding be included as an optional item in the invoice for dues next March (1931).
5. That the bound volume containing the convention papers should also contain the papers for the semi-annual meeting and such other papers submitted during the year as the Publication Committee may deem of sufficient importance to be preserved in a permanent record.
6. That this bound volume of convention papers should also contain the Engineering Index for the entire year (which would be approximately 150 pages) rearranged according to subjects.
7. This publication, one volume a year of about 1000 pages, would be the TRANSACTIONS of the American Society for Steel Treating.
8. If above suggestions are approved, the new publication will no

longer be the complete Transactions of the Society, but, due to the broad application to progress in the metals industry, it is further suggested that the new publication be called METAL PROGRESS.

9. That the function of the Publication Committee shall be to judge the papers for presentation at annual conventions, at sectional meetings, and for the selection of material to be included in the bound volume of the proceedings of the Society.

10. That the Board of Directors place responsibility for the contents of METAL PROGRESS upon the National Office and the Editorial Department of the publication.

Upon motion properly made, seconded and unanimously carried the following organization resolution was adopted:

"Resolved in order to comply with the laws of Ohio, in which the Directors of the Society elect their own officers, it is hereby resolved that the following officers be elected for the American Society for Steel Treating for 1930:

R. G. Guthrie—President
J. M. Watson—Vice-President
W. H. Eisenman—Secretary
A. Oram Fulton—Treasurer."

Confirmation of appointments of National committeemen—

The committeemen nominated by President Guthrie and submitted to the Board members have accepted appointment. The addition is the acceptance of the chairmanship of the Publication Committee by V. O. Homerberg of M. I. T. Mr. W. B. Coleman is to continue as chairman of the Meetings and Papers Committee. The committees in full are as printed in the January issue of the TRANSACTIONS.

It has been the custom of the Board in the past to continue the co-operative committee appointments as indicated in the TRANSACTIONS without change. President Guthrie then presented to the Board the new appointments of members to the national committees, these appointments being the same as had been previously submitted to the Board and ratified by mail with the exception of Mr. V. O. Homerberg as chairman of the Publication Committee.

Upon motion properly made, seconded and unanimously carried, the appointments were approved.

Upon motion properly made, seconded and unanimously carried, the name of the HANDBOOK, published by the American Society for Steel Treating, was changed to NATIONAL METALS HANDBOOK.

Upon motion properly made, seconded and unanimously carried, the following recommended practices were advanced from tentative recommended practices to recommended practices:

1. Recommended Practice for the Heat Treatment of Dies for Die Castings
2. Recommended Practice for the Heat Treatment of Carbon Steels—S.A.E. Series
3. Recommended Practice for the Heat Treatment of Carbon Steel Castings
4. Recommended Practice for the Heat Treatment of Alloy Steel Castings

5. Recommended Practice for the Heat Treatment of Plain Carbon and Alloy Spring Steels
6. Definitions of Terms Relating to Heat Treatment Operations

Upon motion properly made, seconded and unanimously carried, it was decided that the National Western Metal Congress and the National Western Metal Exposition should be held the week of February 16, 1931, in the Civic Auditorium, San Francisco.

On motion made, seconded and unanimously carried the meeting adjourned until 10:00 a. m. February 6.

MINUTES OF MEETING OF THE BOARD OF DIRECTORS

HOTEL PENNSYLVANIA, FEBRUARY 6, 1930—10:00 A. M.

All Board members were present except Dr. Jeffries.

The Board of Directors first gave consideration to the report of the Finance Committee as presented by the chairman, Mr. Fulton.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that the Board of Directors write off the accounts as submitted was approved.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that the inventory figure be set at \$10,966.33 was accepted.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that \$336.17 be written off as depreciation on the office furniture and fixtures and that the value placed on them should be \$2,000.00, was approved.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that the Profit and Loss Statement of the Western Metal Show be accepted, was approved.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that the Profit and Loss Statement of the 1929 Cleveland Convention be accepted, was approved.

Upon motion properly made, seconded and unanimously carried, the balance sheet for 1929, as well as the Profit and Loss Statements, were approved, subject to such minor adjustments as may be made by the auditors or in later actions of the Board.

Upon motion properly made, seconded and unanimously carried, the recommendation of the Finance Committee that the terms of all invoices rendered by the Society should be 30 days net, was approved.

The Finance Committee then submitted the budget for 1930 and after careful consideration, a motion was made, seconded and unanimously carried that the budget as presented by the Committee should be approved. The budget is:

Budget for the Year 1930

INCOME

Membership Dues	\$ 69,000.00
Sustaining Exhibit Membership	5,000.00
TRANSACTIONS Advertising	58,000.00
TRANSACTIONS Subscriptions	2,300.00
TRANSACTIONS Sales	2,000.00
Reprints	2,500.00

Bindery	1,500.00	
Books Purchased	2,200.00	
General Index	35.00	
Books Published	8,000.00	
National Metals Handbook	2,000.00	
National Metals Handbook Advertising	7,000.00	
Extension Division	12,000.00	
Interest Earned	9,000.00	
Interest Earned—H. M. Howe Medal Fund	212.50	
Discounts Earned	1,000.00	
Sundry Income	300.00	
1930 Convention	100,000.00	\$282,047.50

EXPENSE

Apportionment of Dues to Chapters	\$ 28,300.00	
Support to Chapters	1,000.00	
TRANSACTIONS	55,600.00	
Reprints	1,500.00	
Bindery	1,500.00	
General Index	50.00	
Books—For Library	250.00	
Purchases for Resale	1,900.00	
Books Published	5,000.00	
National Metals Handbook	12,350.00	
Howe Medal Fund Expense	50.00	
Campbell Memorial Lecture Exp.	500.00	
Extension Division	12,000.00	
Semi-Annual Meeting and Western Metal Congress	1,000.00	
National Committees	5,000.00	
Directors' Expense	3,500.00	
President's Office	1,000.00	
Treasurer's Office	6,500.00	
Audit	750.00	
Secretary's Office	21,900.00	
General Expense	12,950.00	
Reserves	19,447.50	
1930 Convention	90,000.00	\$282,047.50

Upon motion properly made, seconded and unanimously carried, the recommendation that the Finance Committee be given permission to exchange the \$15,000.00 Cleveland Trust Securities and the \$5,000.00 University Club Land Certificates for other securities more suitable for Society investments and that they also endeavor to do the same with the Fidelity Land Trust Securities to the amount of \$10,000.00, was approved.

Upon motion properly made, seconded and unanimously carried, the Board of Directors approved the recommendation of the Finance Committee that the Society should establish, when convenient, a savings account with the Central Trust Company of Cambridge, Mass.

Upon motion properly made, seconded and unanimously carried, the thanks of the Board of Directors was expressed to the Finance Committee for the capable and splendid manner in which they handled the financial affairs of the Society, together with their recommendations to the Board.

Upon motion properly made, seconded and unanimously carried, the Board approved that the Winter Meeting for 1931 should be held simultaneously with the National Western Metal Congress in San Francisco the week of February 16, 1931.

Upon motion properly made, seconded and unanimously carried, the Board approved that Messrs. Fulton and Eisenman be appointed as a committee with power to act in the selection of the 1931 convention city; cities especially to be considered are Atlantic City and Boston, provided satisfactory arrangements can be made.

Upon motion properly made, seconded and unanimously carried, Dr. Marcus

Grossmann, chief metallurgist, Central Alloy Steel Corporation, was invited to be the Campbell Memorial Lecturer for 1930.

Upon motion properly made, seconded and unanimously carried, the Board approved that a charter as a chapter be granted to the New Jersey Group and that they be congratulated on the splendid showing they have made so far and that they have the best wishes of the Board for their continued success.

Upon motion properly made, seconded and unanimously carried, the Board approved the advancement of the Columbus Group to that of a chapter rating.

Upon motion properly made, seconded and unanimously carried, the Board recommended a change in the Constitution providing for the establishment of an initiation fee on January 1, 1932, for new members in the Society to the amount of \$15.00. This initiation fee is not to apply to sustaining and junior members.

On motion made, seconded and unanimously carried, the meeting adjourned.

W. H. EISENMAN, *Secretary*.

FINANCIAL STATEMENT OF THE AMERICAN SOCIETY FOR STEEL TREATING FOR THE YEAR 1929

The official report of Ernst and Ernst, certified public accountants, covering the results of their audit of the books of the society, is submitted herewith. The original copy of this report is on file at the society offices in Cleveland and is open for the inspection of any interested members.

The auditors certify as follows:

"We have examined the books of account and record pertaining to the assets and liabilities of the American Society for Steel Treating—Cleveland, as of the close of business December 31, 1929, and submit herewith our report. The scope of our examination did not include a detailed audit of all of the membership dues records, sales and purchase invoices, etc., our work in this respect consisting of test checks.

"We include as part of this report Balance Sheet, setting forth the assets and liabilities of the society as of the close of business December 31, 1929, subject to the following comments:

"Cash on hand was verified by actual count and cash on deposit by direct correspondence with the depository banks and reconciliation of the balances reported with the balances shown by the society's records at December 31, 1929. We traced all recorded cash receipts for the year 1929 directly into the bank deposits and all recorded cash disbursements for the same period were found to be supported by cancelled bank checks, with the exception of checks outstanding at December 31, 1929, and further supported by invoices and other data on file.

"Securities owned, consisting of U. S. Government and other bonds and land trust certificates, are stated at cost value and were verified by direct communication with The Cleveland Trust Company, which company held the securities for safekeeping.

"Unpaid balances and accounts receivable were proved as to total by trial balance, but we do not respond with the recorded debtors to further verify

the accuracy of the society's records. The allowance provided for doubtful accounts, in our opinion, is sufficient.

"The inventory valuation of bound volumes of publications, paper stock, etc., on hand and at printers, is based upon physical inventories taken and priced under the direction of the management at cost, as indicated by data examined by us.

"Included as other assets are officers' and employees' accounts, advances to chapters, etc., in the aggregate amount of \$3,309.56.

"Furniture and fixtures are stated in the accompanying Balance Sheet at a value of \$2,975.50, an allowance for depreciation in the amount of \$336.17 being charged against current operations.

"Under the caption of Deferred are prepaid convention expense and improvements to leased property, which, in our opinion, represent items properly chargeable against future operations of the society.

"The liabilities, as stated, include provision for all obligations of the society at December 31, 1929, disclosed by the records examined and information obtained by us.

"We have also prepared from the society's records and submit herewith Statement of Income and Expense for the year ended December 31, 1929. We checked all of the vouchers for the year but we did not make a detailed audit of all of the accounts represented in this statement.

"Subject to the foregoing, We Hereby Certify, that we have examined the books of account and record of the American Society for Steel Treating—Cleveland, as of the close of business December 31, 1929, and that, in our opinion, based upon the records examined and information obtained by us, the accompanying Balance Sheet sets forth the financial position of the society as of the date named."

(L. S.)

ERNST & ERNST, *Certified Public Accountants.*

BALANCE SHEET, DECEMBER 31, 1929

ASSETS			
CASH			
ON HAND			
Petty Cash Fund		\$ 96.01	
ON DEPOSIT			
Savings Accounts	\$ 26,231.42		
Commercial Account	1,180.29	27,411.71	\$ 27,507.72
SECURITIES (At Cost)			
U. S. Government Securities	\$ 27,689.70		
Other Securities	127,232.38	\$154,922.08	
Accrued Interest		2,417.08	157,339.16
ACCOUNTS RECEIVABLE			
Advertising	\$ 3,297.17		
Miscellaneous	1,530.54		
Convention—1929	1,442.69		
Convention—1928	172.85	\$ 6,443.25	
Less: Allowance for Doubtful Accounts		296.35	6,146.90
INVENTORY (Certified by Management)			
Bound Volumes of "Transactions," Paper Stock, Members' Pins and other Bound and Unbound Books			10,966.33
OTHER ASSETS			
Officers' and Employees' Accounts, Advances to Chapters, etc.			3,309.56
PERMANENT (Book Value)			
Office Furniture and Fixtures			2,975.50

DEFERRED

Prepaid 1930 Convention Expense	\$ 1,476.21	
Improvements to Leased Property	465.00	1,941.21
		<u>\$210,186.38</u>

LIABILITIES

ACCOUNTS PAYABLE

For Purchases, Expenses, etc.	\$ 3,642.04	
For Apportionment of Dues to Chapters	789.85	
Members' Credit Balances	166.43	\$ 4,598.32

RESERVES

For, Conventions	\$ 20,000.00	
For Contingencies	20,000.00	
For H. M. Howe Medal Fund	5,000.00	
For General Index	400.00	45,400.00

SURPLUS

Balance December 31, 1929		160,188.06
		<u>\$210,186.38</u>

(Note A) This Balance Sheet is subject to the comments in our "Certificate," included in and made a part of this report.

INCOME AND EXPENSE, YEAR ENDED DECEMBER 31, 1929

INCOME

1929 CONVENTION—CLEVELAND

Space Rentals	\$ 62,423.75	
Special Services	29,892.22	
Banquet	1,405.00	
Gate Receipts, Tickets and Passes	1,113.90	
Miscellaneous	350.00	\$ 95,184.87

"TRANSACTIONS"—MONTHLY PUBLICATION

Advertising	\$ 49,593.11	
Reprints	3,073.52	
Subscriptions	2,275.07	
Sales other than Subscriptions	1,987.41	
Bindery	1,680.78	58,609.89

WESTERN METAL SHOW—LOS ANGELES

Space Rentals	\$ 32,864.68	
Special Service	3,466.15	
Banquet	1,860.00	
Program Advertising	1,230.00	
Gate Receipts	698.75	40,119.58

MEMBERSHIPS

Membership Dues	\$ 54,241.47	
Sustaining Exhibit Membership	5,225.00	\$ 59,466.47
Less: Apportionment of Dues to Chapters	23,348.30	36,118.17

Extension Division	20,965.00
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BOOKS PUBLISHED

John F. Keller Book	\$ 9,635.55	
Dr. W. H. Hatfield Book	1,023.80	
H. B. Knowlton Book	593.55	
Bureau of Standards Book	586.21	
C. R. Wohrman Book	468.59	12,307.70

Interest Earned	8,516.83
Books Purchased and Resold	2,076.89
Data Sheets, Binders and Books	1,858.86
Discount Earned	900.39
Miscellaneous	246.59
Recovery on Account previously charged off	16.53

TOTAL INCOME

\$276,921.30

EXPENSE

AS SHOWN BY EXHIBIT

1929 Convention—Cleveland	\$ 82,126.16
"Transactions"—Monthly Publications	51,067.09
Western Metal Show—Los Angeles	36,298.90
Secretary's Office	20,567.51

Treasurer's Office	6,180.57	
President's Office	686.59	
Extension Division	17,819.51	
General Expense	12,470.14	
Data Sheets	3,721.84	
Recommended Practice	3,631.66	
Books Published	3,177.05	
Directors' Expense	2,964.80	\$240,711.82
Books Purchased for Resale		1,831.96
Reprints Purchased for Resale		1,510.22
National Committee Publications		1,169.27
Support of Chapters		901.78
H. M. Howe Medal Fund Expense		610.33
E. D. Campbell Memorial Lecture Expense		500.00
Books Purchased for Library		173.03
Pencils, Pins and Buttons		24.14
TOTAL EXPENSE		\$247,432.55
NET PROFIT		\$ 29,488.75

QUAD CHAPTER MEETING

The second annual joint meeting of the Philadelphia, New York, Lehigh Valley and New Jersey chapters will be held in Newark, New Jersey, on May 23rd. The first meeting of these four chapters was held in Bethlehem, Pa., in May of last year. At that time more than 400 members from the out-of-town chapters journeyed to Bethlehem where they joined forces with almost 200 members and guests of the Lehigh Valley chapter in one of the most successful gatherings ever sponsored by chapters of the American Society for Steel Treating. An even larger attendance is hoped for this year in Newark.

At the time of the 1929 meeting, the New Jersey group was only two months old and had but 63 members. Today, the group is officially a chapter of the society and has a membership of over 180. John F. Wyzalek, Hyatt Roller Bearing Co., Harrison, N. J., and a charter member of the group, is chairman of the New Jersey chapter committee on arrangements for this meeting.

The program as so far announced includes a trip through the Western Electric Company's plant at Kearney in the morning, a luncheon at the Newark Elks' Club at 12:30 P. M., a trip through the plant of the Wright Aeronautical Corp., Paterson, in the afternoon followed by the dinner at 6:30 P. M. at the Elks' Club in Newark.

F. F. Lucas, Bell Telephone Research Laboratories, will give his impressions of Japan as a coffee talk. Mr. Lucas attended the World Engineering Congress in Tokyo last fall. Horace C. Knerr, consulting metallurgist and member of the Philadelphia chapter, will then talk on "Aircraft Metallurgy", a subject with which he is very familiar. Professor G. B. Waterhouse, Massachusetts Institute of Technology, will serve as technical chairman of the session.

A cordial invitation to this meeting is extended to every member of the society by members of the participating chapters.

The Syracuse, Rochester and Southern Tier chapters of the Society will hold a joint meeting at Cornell University, Ithaca, N. Y., on April 25. Scheduled events include a tour of inspection of the College of Engineering and an interesting technical program. All members of the society are cordially invited to attend.

April

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